The U.S. Geological Survey Streamflow and Observation-Well Network in Massachusetts and Rhode Island

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ABSTRACT

The U.S. Geological Survey began systematic streamflow monitoring in Massachusetts nearly 100 years ago (1904) on the Connecticut River at Montague City. Since that time, hydrologic data collection has evolved into a monitoring network of 103 streamgage stations and 200 ground-water observation wells in Massachusetts and Rhode Island (2000 water year). Data from this network provide critical information for a variety of purposes to Federal, State, and local government agencies, engineering consultants, and the public. The uses of this information have been enhanced by the fact that about 70 percent of the streamgage stations and a small but increasing number of observation wells in Massachusetts and Rhode Island have been equipped with digital collection platforms that transmit data by satellite every 4 hours. Twenty-one of the telemetered streamgage stations are also equipped with precipitation recorders. The near real-time data provided by these stations, along with historical data collected at all stations, are available over the Internet at no charge.

The monitoring network operated during the 2000 water year was summarized and evaluated with respect to spatial distribution, the current uses of the data, and the physical characteristics associated with the monitoring sites. This report provides maps that show locations and summary tables for active continuous record streamgage stations, discontinued streamgage stations, and observation wells in each of the 28 major basins identified by the Massachusetts Executive Office of Environmental Affairs and five of the major Rhode Island basins. Metrics of record length, regulation, physiographic region and physical and land-cover characteristics indicate that the streamflow-monitoring network represents a wide range of drainage-area sizes, physiographic regions, and basin characteristics. Most streamgage stations are affected by regulation, which provides information for specific water-management purposes, but diminishes the usefulness of these stations for many types of hydrologic analysis. Only 26 of the 103 active streamgage stations operated by the U.S. Geological Survey in Massachusetts and Rhode Island are unaffected by regulation; of these, 17 are in Massachusetts and 9 are in Rhode Island. The paucity of unregulated stations is particularly evident when the stations are grouped into five drainage-area size classes; the fact that about half of these size classes have no representative unregulated stations underscores the importance of establishing and maintaining stations that are unaffected by regulation. The observation-well network comprises 200 wells; 80 percent of these wells are finished in sand and gravel, 19 percent are finished in till, and 1 percent are finished in bedrock. About 6 percent of the wells are equipped with continuous data recorders, and about half of these are capable of transmitting data in near real time.

INTRODUCTION

The U.S. Geological Survey (USGS) MA–RI District has collected streamflow and ground-water-level data in Massachusetts and Rhode Island for nearly 100 years. Data are collected through the operation of a network of streamflow gages and observation wells in cooperation with other Federal, State, and local government agencies. Data from this network provide critical information for water supply, the management and regulation of dam storage and release, the magnitudes and frequencies of flood flows and low flows, trends in hydrologic conditions associated with rapidly changing land use, and for many other purposes. The network also provides regional information from which estimates of hydrologic characteristics at ungaged sites can be obtained. Thus, the network serves the dual purpose of obtaining site-specific data and regional data. Often, however, site-specific data needs are incompatible with regional data requirements. For example, a station operated to monitor streamflow below a dam may not provide information useful for developing regional-flow equations. Streamgage stations and observation wells must be maintained to reflect a wide range of hydrologic conditions to meet the needs of the users of this information within the constraints of the resources available.

Measuring discharge on the Saugus River at the Saugus River Ironworks, Saugus, Massachusetts (station number—01102345).

Purpose and Scope

This report provides a broad description and characteristics of the long-term streamgage and the observation-well network required to meet water-resource planning and management needs. The purpose of this report is to provide an overview of the existing continuously recording streamgage station and observation well network operated by the USGS MA–RI District office. This network is evaluated with respect to current uses of the data, spatial distribution, and physical characteristics of the gaged basins. The report also describes trends in the historical operation of the network, funding sources, and modernization with emphasis on the streamgage stations. Most conditions presented in this report are current as of the 2000 water year (October 1, 1999, to September 30, 2000); however, some conditions, such as equipment modernization, have been updated through the 2002 water year. The report includes maps and summary tables of active streamgage stations, discontinued streamgage stations, and observation wells for each of the 28 major basins identified by the Massachusetts Executive Office of Environmental Affairs (EOEA) and five major Rhode Island basins (Appendix 1).

Acknowledgments

The operation of the monitoring network in Massachusetts and Rhode Island is funded through cooperative agreements between the USGS and other Federal, State, and local government agencies. In the 2000 water year, the USGS received financial support from the U.S. Army Corps of Engineers (ACOE); State of Massachusetts—Department of Environmental Management (MADEM), Department of Environmental Protection (MADEP), Metropolitan District Commission (MDC), and the Towns of Dartmouth, Franklin, and Rockport; State of Rhode Island—Water Resources Board (RIWRB) Department of Environmental Management

(RIDEM), and the Providence Water Supply Board (PWSB). The USGS also receives non-monetary services from the Cape Cod Commission, the Cooperative Extension of Martha's Vineyard, and the Nantucket Land Council to support the observation-well network in those areas. The authors are grateful to USGS employees Peter Steeves and Tomas Smieszek for compiling geographic information for the hydrologic monitoring network.

Previous Studies

Much of the information in this report was compiled from information provided in the USGS annual data reports (for example, Socolow and others, 2001). The annual data reports contain information on station descriptions; hydrologic conditions for the year; daily-streamflow values; daily, bimonthly, or monthly ground-water-level data; and statistical information about the current year's data relative to the historical data collected at a site. Annual data reports also provide information on discontinued stations, partial record sites, and miscellaneous measurements made during the current water year, water-quality data, and information about how the data were collected. Partial-record sites and miscellaneous measurements provide data to augment the continuous monitoring network; partial-record sites are typically operated for specific hydrologic investigations for relatively short periods and, therefore, are not described further in this report.

The USGS does not operate a long-term water-quality monitoring network in Massachusetts or Rhode Island. Water-quality data are collected and published in annual data reports or in specific hydrologic investigation reports. The need for a consistent water-quality monitoring network for Massachusetts streams and ponds, and the scope and specifications of such a network are described by DeSimone and others (2001).

An evaluation of the national streamgage-monitoring network and its associated Federal interest was prepared for Congress (U.S. Geological Survey, 1999). The Federal interests of a hydrologic monitoring network are to quantify (1) interstate and international transfers of water, (2) flood warning and forecasting, (3) water budgets of major watersheds, (4) long-term hydrologic changes (trends), and (5) water quality. Although the need for streamflow data has continued to increase over time, the report for Congress pointed out the total number of streamgage stations has declined since the 1970s. In particular, the loss of streamgage stations with 30 or more years of record diminishes the ability to understand the long-term changes taking place in the environment or relations between climate, land use, and streamflow. Stations have been eliminated from the national network not because of their hydrologic value, but because of the financial constraints of cooperating agencies. The report to Congress also identified the need to modernize the streamgage network, harden streamgage installations from structural damage during floods, provide backup systems for near real-time dissemination of data, extend rating curves, and operate precipitation gages in conjunction with streamgage stations.

Streamgage station on the Ipswich River at South Middleton, Massachusetts (station number—01101500), during record high flows in March 2001.

Wahl and others (1995) described the national uses of streamflow data collected at 7,292 streamgage stations in operation as of 1994. The national evaluation indicated that most data were used for regional hydrologic or hydrologic system investigations and that data from 80 percent of the stations were used in two or more of nine principal-use categories. The national network is supported by over 600 Federal, State, and local agencies, which provide 50 percent or more of the funds needed to operate these stations. The USGS funds the remainder through the Federal-State Cooperative Program; fewer than 10 percent of the streamgage stations are funded entirely by USGS. Thomas and Wahl (1993) concluded that the national network was operated in an efficient and cost-effective manner.

A streamgage-network analysis in the MA–RI District was completed in the early to mid-1980s (Gadoury and others, 1985). This analysis focused on the cost effectiveness of the network and the potential for reducing the numbers of streamgage stations by estimating flow by unit-flow routing from upstream or downstream stations or regression models that estimate flow from physical basin characteristics. This analysis concluded that the alternative flow-estimation techniques examined could not provide the same level of accuracy as a continuous streamgage station. This conclusion would limit most uses of these data. Of seven sites identified by Gadoury and others (1985) as candidates for alternative flow estimation, only one site, Cadwell Creek near Belchertown (0117490) in central Massachusetts, was discontinued (in 1997). The report concluded that alternative routes for site visits would not produce appreciable costs savings in the operation of the streamgage network. The network analysis report identified a streamgage on Cape Cod (Herring River at North Harwich—01105880) that could be replaced with an alternative site less influenced by regulation and evaporation from an upstream pond. The Herring River station was subsequently replaced in 1988 with a station on the Quashnet River at Waquoit Village (011058837) on Cape Cod.

Measuring discharge from a cableway, Squannacook River near West Groton, Massachusetts (station number—01096000).

NETWORK OBJECTIVES

Streamgage stations and observation wells provide data for a variety of purposes for water-resources planning and design, hydrologic research, and operation of water-resources projects. To meet these needs, the monitoring network must provide consistent long-term data and provide ready access to the data. The process begins by employing a skilled staff to maintain and operate the network by using state-of-the-art equipment and culminates with storage of the data collected through the network in an accessible and dependable database.

Most hydrologic data collected by the USGS over the last 100 years is stored in the USGS National Water Information System (NWIS) database. In 2001, the NWIS database contained streamflow data for about 21,000 sites, water-level data from more than 1,000,000 wells, and chemical data from surface water and ground water at 338,000 sites (Brooks, 2001). In 1994, the Automated Data Processing System (ADAPS) part of NWIS (continuously recorded data) stored over 400,000 station-years of record (Wahl and others, 1995). ADAPS contains mean daily discharge data for 198 streams and rivers in Massachusetts and Rhode Island; these data represented about 6,000 station-years of record as of the 2000 water year. The NWIS database also includes the ground-water site inventory (GWSI), which contains about 31,000 sites (the GWSI contains all site locations and nonautomated ground-water-level measurements), and the water-quality database (QWDATA), which contains data from 4,500 sites in Massachusetts and Rhode Island. Data stored in NWIS is typically available at no charge, and most data can be directly accessed through the Internet.

> In my work, whether as a real estate broker in Berkshire Hills of western Massachusetts, as a Conservation Commissioner for my town of Stockbridge, or as a local watershed project coordinator for the Housatonic Valley Association, USGS map products and on-line web sites provide exceptional value for my tax dollar because they empower all of us to do far better work than we could do on our own. That's what I have always thought government was suppose to do, you-all have hit the mark dead center.
>
> *—Shepley W. Evans, Stockbridge, Massachusetts; in U.S. Geological Survey, 1999, p. 10*

Streamflow data in this report were categorized into 1 or more of 11 principal uses (fig. 1). Qualitative-use categories were determined from (1) cooperating agency's reported reasons for funding a station, (2) data requests, (3) hydrographers' knowledge, and (4) responses to questionnaires from Massachusetts EOEA Watershed

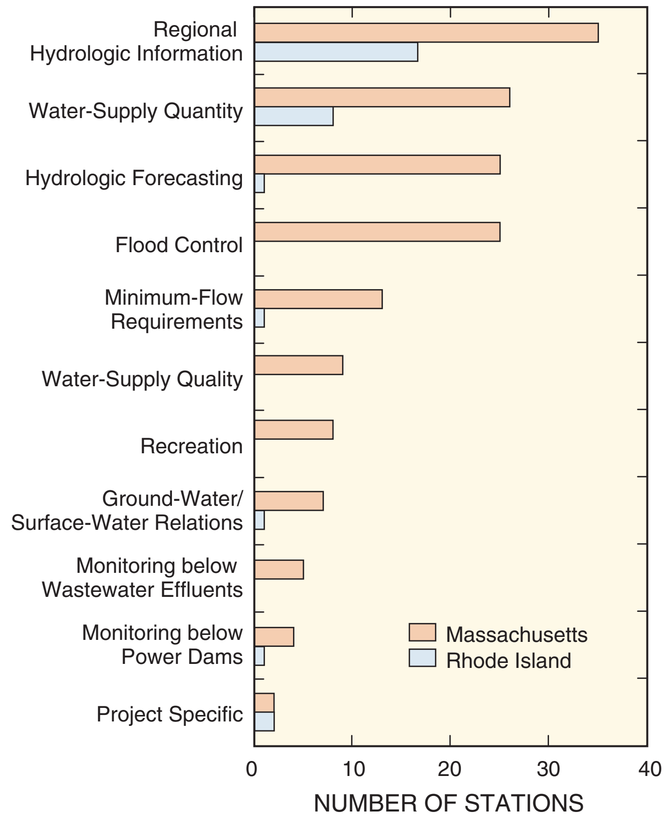

Figure 1. Number of U.S. Geological Survey streamgage stations operated in Massachusetts and Rhode Island by category of data use, 2000 water year.

Team leaders and cooperating agencies about how they use the data. The categories are generally listed in order of the number of stations in each use category.

The distribution of active stations in the 2000 water year among each of the 11 categories indicates that most data are used for regional hydrologic information (45 percent of all stations). Stations were not assigned exclusively to one use category; rather, the station was assigned to all use categories that apply to it. About 55 percent of all stations provide information for two or more categories. Eighteen stations in Massachusetts and one station in Rhode Island provide data for three or more use categories.

Regional hydrologic information: These stations provide data that can be used to develop relations between basin characteristics and hydrologic conditions, extrapolate short-term streamflow data to reflect long-term conditions, and assess long-term hydrologic trends. STREAMSTATS (Ries and others, 2000), an application for determining flow characteristics at ungaged sites in Massachusetts, is an example of regional hydrologic use of the streamgage data. Regional hydrologic analysis requires data that are unaffected, or are minimally affected, by regulation under flow conditions appropriate for the regional analysis under consideration. Thirty-five stations in Massachusetts and 17 stations in Rhode Island provide data for this type of use.

Water-supply quantity: These stations provide data to state agencies and water suppliers to assess public water supplies. These stations are on major tributaries to supply reservoirs or the outlet from the reservoir, or both, and in rivers that have surface-water withdrawals. Twenty-six stations in Massachusetts and eight stations in Rhode Island provide data for this type of use.

Hydrologic forecasting: Many stations provide information useful in flood forecasting and flood warning. These stations play a key role in efforts by Federal, State, and local agencies to protect the lives and welfare of the public. The National Weather Service (NWS) relies on these stations as part of their flood-forecasting system.

Stage-discharge control for monitoring flows for water supply in the Quabbin Reservoir on East Branch Swift River near Hardwick, Massachusetts (station number—01174500).

The streamflow-monitoring network provides critical information on peak flows essential for designing bridges and culverts, flood zoning, and land-use planning.

Historical streamflow data are used by the NWS to calibrate river-forecasting models. Flood stages identified by the NWS are displayed on the USGS Web pages to provide immediate access to users during floods. Twenty-five stations in Massachusetts and one station in Rhode Island provide data for this type of use.

Flood control: These stations are below flood-control dams and are used by water managers for making operational decisions on outflow from the dam. The ACOE is the principal user of these data. Twenty-five stations in Massachusetts and no Rhode Island stations provide data for this type of use.

Minimum-flow requirements: These stations are used to monitor streamflow affected by water-supply withdrawals. Streamflow data is increasingly important for habitat protection, and maintaining streamflow has become a focal issue for water-supply planners and managers since the passage of the Massachusetts Water Management Act of 1986 (Massachusetts Water Management Act, 1986, accessed July 17, 2002). Many of these stations have been established as a requirement for permitting new withdrawals and have been in operation for a relatively short time. Some stations in this category are used to monitor streamflow for fish migration. Thirteen stations in Massachusetts and one station in Rhode Island provide data for this type of use.

Flooding in Southbridge, Massachusetts, in August 1955 following back-to-back Hurricanes Connie and Diane that dropped about 20 inches of rain in the Quinebaug River basin in a 2-week period. [Photo taken by Jim Houghton, courtesy of Richard Whitney (dickwhitney@meganet.net).]

Damage caused by the August 1955 flood on Mechanic Street, Southbridge, Massachusetts. (Photo taken by Donald Whitney, courtesy of Richard Whitney.)

Water-supply quality: Streamflow data, along with the water-chemistry data, provide essential information for evaluating water-quality conditions in rivers and receiving-water lakes, reservoirs, and estuaries. Nine stations in Massachusetts and none in Rhode Island provide data for this type of use.

Recreation: Streamgage stations have not been operated solely for the purpose of recreational use; however, stations provide data to the commercial recreation industry, particularly white-water rafting adventure companies and for noncommercial recreational uses such as canoeists, rafters, and anglers. Noncommercial uses are difficult to estimate and are not included in this category; however, anecdotal information indicates that use of streamflow data for these purposes is extensive. Eight stations in Massachusetts and no stations in Rhode Island provide data for this type of use.

Ground-water/surface-water relations: Stations near observation wells could help provide data on the interaction between ground- and surface-water resources. Several project-specific water-resource investigations use data that relate ground-water conditions to streamflow; however, no continuous statewide programs exist to evaluate this relation. Seven stations in Massachusetts and one Rhode Island station provide data for this type of use.

Monitoring below wastewater effluents: These stations are on streams near effluents from wastewater-treatment plants. The stations provide data to help assess the impact of wastewater effluents on receiving waters, and in recent years, have become important for establishment of total maximum daily loads (TMDL) allocations to improve water-quality conditions of surface waters. Five stations in Massachusetts and none in Rhode Island provide data for this type of use.

Monitoring below power dams: These stations were established to satisfy a legal responsibility of the USGS or its cooperator to monitor streamflow below hydroelectric power-generating facilities for the Federal Energy Regulatory Commission (FERC). Four stations in Massachusetts and one Rhode Island station provide data for this type of use.

Project specific: Stations assigned to this category are typically short-term stations that have been installed to meet a specific project need. The number of active project stations varies from year to year. These stations are generally discontinued after the data needs of the project are satisfied. During the 2000 water year, two stations in Massachusetts and two stations in Rhode Island provided data for this type of use.

The streamgage station (stage sensor is in the pipe protruding from the cement retaining wall) below the fish ladder on Whitmans Pond outlet in East Weymouth, Massachusetts (station number—01105608), provides data to help determine water-supply availability and flow for spring and fall herring runs.

National Interests

The USGS has identified five core interests for its National Streamflow Information Program (NSIP). The NSIP interests are (Hirsch and Norris, 2001; U.S. Geological Survey, 1999):

- **Interstate and international waters:** Provide data to support interstate compacts, court decisions, and international treaties on rivers at state-line crossings, compact points and international boundaries.
- **Flood forecasting:** Provide real-time stage and discharge data required to support flood forecasting by the NWS.
- **River basin outflows:** Provide data for resource managers to account for streamflow from each of the Nation's 350 major river basins to the next downstream basin, estuary, ocean, or Great Lakes.
- **Sentinel watersheds:** Provide data that describe the changing status of streamflow as it varies in response to climate, land use, and water use in the 800 watersheds across the country that are relatively unaffected by flow regulation or diversion and typify major ecoregions and river basins.
- **Water quality:** Provide data to support three national USGS water-quality networks on (1) the major rivers of the Nation, (2) intermediate-sized rivers, and (3) small pristine watersheds.

The MA–RI District Office, in conjunction with the USGS Office of Surface Water, has identified 23 streamgage stations in Massachusetts and 2 streamgage stations in Rhode Island that meet NSIP interests (table 1, fig. 2). Three streamgage stations were identified for discharge information at interstate boundaries, 17 stations were identified for flood-forecasting needs, 4 stations were identified to provide water-budget data for major river basins, 3 stations were identified for monitoring long-term hydrologic trends, and 5 stations were identified to support USGS water-quality networks. Most potential NSIP stations are currently part of the existing streamflow-monitoring network, three new stations were identified for flood-forecasting purposes, and one discontinued station was identified for reactivation to collect discharge data at an interstate boundary.

Stations that meet one or more of the NSIP interests and are currently operated in cooperation with other Federal, State, and local agencies may be eligible for additional funding from the USGS in the future. The U.S. Congress has recognized that the disproportional decline in the number of long-term unregulated streamgage stations can adversely affect the achievement of the goals of this network and that new strategies are needed to fund the continued operation of priority stations (Hirsh and Norris, 2001).

Table 1. Streamgage stations in Massachusetts and Rhode Island identified for inclusion in the U.S. Geological Survey National Streamflow Information Program (NSIP)

[**Status:** A-Active, I-Inactive, N-New]

Station number	Station name	Status	Interstate boundary	Flood fore-casting	Basin water budgets	Long-term trend	Water quality
Massachusetts							
01095220	Stillwater River near Sterling	A					●
01096500	Nashua River at East Pepperell	A		●			
01097000	Assabet River at Maynard	A		●			
01099500	Concord River below River Meadow Brook at Lowell	A		●			
01100000	Merrimack River below Concord River at Lowell	A	●	●	●		●
01100561	Spicket River near Methuen	A		●			
01102500	Aberjona River at Winchester	A					●
01103500	Charles River near Dover	A		●			
01104500	Charles River at Waltham	A			●		
01104615	Charles River above Watertown Dam at Watertown	A					●
01105000	Neponset River at Norwood	A		●			
01110500	Blackstone River at Northbridge	A		●			
01162500	Priest Brook near Winchendon	A				●	
01170100	Green River near Colrain	A					●
01170500	Connecticut River at Montague City	A	●	●	●		
01172003	Connecticut River below Power Dam at Holyoke	A		●			
01177000	Chicopee River at Indian Orchard	A		●			
01183500	Westfield River near Westfield	A		●			
01197500	Housatonic River near Great Barrington	A		●		●	
01198125	Housatonic River near Ashley Falls	I	●				
MA 100	Merrimack River near Haverhill	N		●			
MA 101	Merrimack River above Lowell	N		●			
MA 102	Connecticut River below Montague City, above Holyoke	N		●			
Rhode Island							
01112500	Blackstone River at Woonsocket	A		●	●		
01117500	Pawcatuck River at Wood River Junction	A				●	

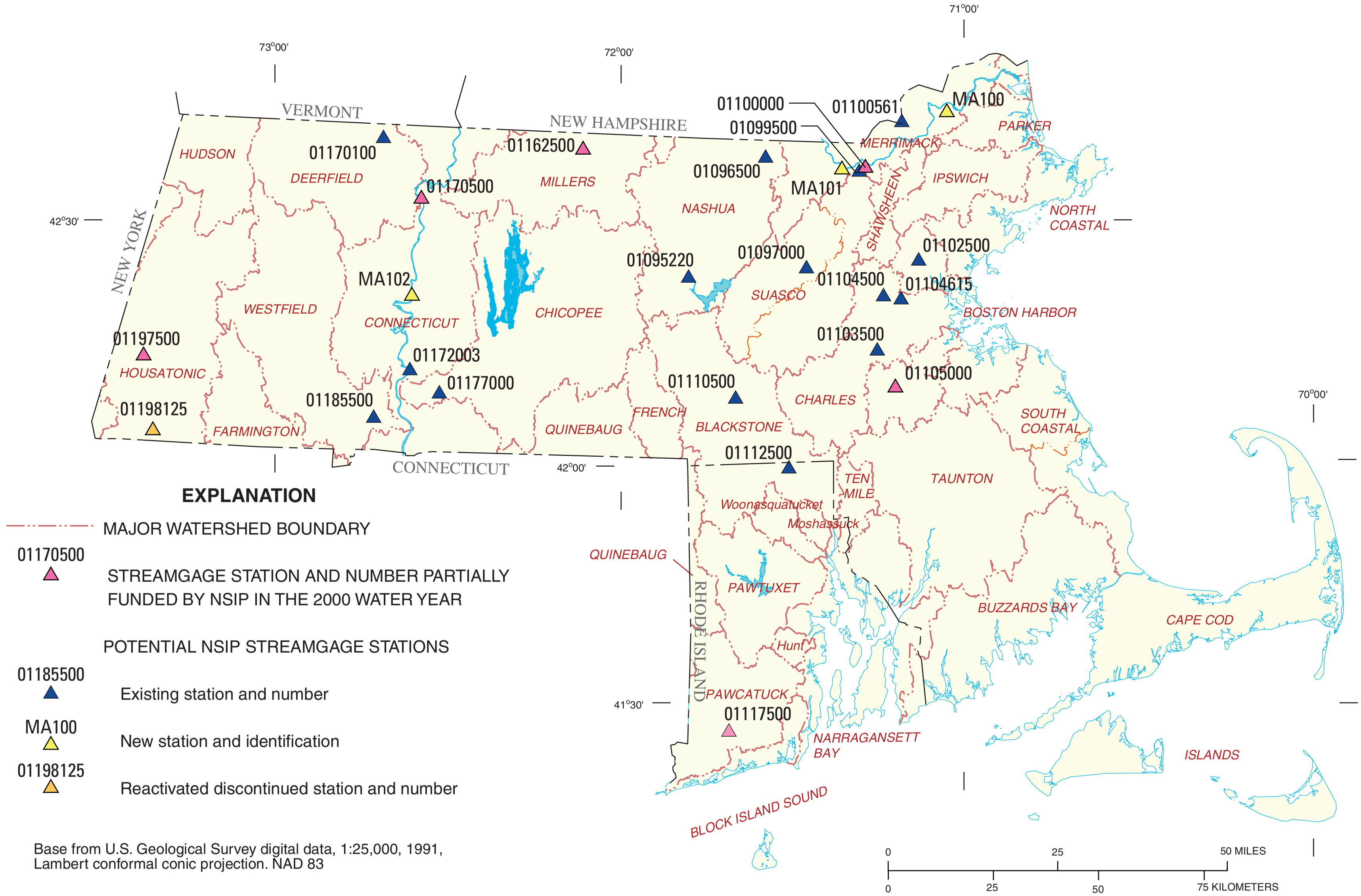

Figure 2. Locations of streamgage stations in Massachusetts and Rhode Island identified for inclusion in the U.S. Geological Survey National Streamflow Information Program (NSIP).

In the late 1980s, a network of streamgage stations was selected for study of surface-water conditions throughout the United States under fluctuations in the prevailing climatic conditions. These stations were designated as the Hydro-Climatic Data Network, or HCDN (Slack and others, 1992; 1994). This network consists of 1,659 streamgage stations throughout United States and its Territories and includes 17 stations in Massachusetts and 7 stations in Rhode Island (table 2). Stations selected for this network were thought to be largely unaffected by artificial diversions, storage, or other synthetic influences and, therefore, were suited to provide reliable data on natural hydrologic responses to fluctuations in climate. The HCDN network includes four stations (01165000, 01173000, 01175500, 01180500) that are appreciably affected by dam regulation or diversion, or both. Streamflow at these stations is likely affected by factors unrelated to climatic conditions. No additional funding has been provided for stations listed in the HCDN network.

Table 2. Streamgage stations in Massachusetts and Rhode Island included in the U.S. Geological Survey national Hydro-Climatic Data Network (HCDN)

Station number	Station Name
Massachusetts Stations	
01162500	Priest Brook near Winchendon
01165000[1]	East Branch Tully River near Athol
01165500	Moss Brook at Wendell Depot
01169000	North River at Shattuckville
01169900	South River near Conway
01170100	Green River near Colrain
01173000[1]	Ware River at Intake Works Near Barre
01174000	Hop Brook near New Salem
01174900	Cadwell Creek near Belchertown
01175500[1]	Swift River at West Ware
01176000	Quaboag River at West Brimfield
01180000	Sykes Brook at Knightville
01180500[1]	Middle Branch Westfield River at Goss Heights
01181000	West Branch Westfield River at Huntington
01198000	Green River near Great Barrington
01332000	North Branch Hoosic River at North Adams
01333000	Green River At Williamstown
Rhode Island Stations	
01106000	Adamsville Brook at Adamsville
01111300	Nipmuc River near Harrisville
01111500	Branch River at Forestdale
01117500	Pawcatuck River at Wood River Junction
01117800	Wood River near Arcadia
01118000	Wood River at Hope Valley
01118500	Pawcatuck River at Westerly

[1]Stations appreciably affected by dam regulation or diversion, or both.

The importance and uses of a national long-term ground-water-level-monitoring network have been described by Taylor and Alley (2002) and Grannemann (2001). An effort to fund a national water-level-monitoring network, referred to as the Collection of Basic Records (CBR), has been underway by the USGS since 1995 (U.S. Geological Survey, accessed July 17, 2002). Like NSIP, the CBR has identified the need for systematic long-term measurement of ground-water levels and the essential information these data provide to water-resources managers, planners, and regulators. Some important activities that use ground-water-level data are the evaluation of changes in ground-water levels over time, forecasts of trends, development of ground-water-flow models, and the design, implementation and monitoring of ground-water management and protection programs (Taylor and Alley, 2002). Observation wells identified for inclusion in the CBR include three wells in Massachusetts and one well in Rhode Island (table 3). Limited funding has been provided annually from the USGS NSIP program to support the operation of these wells.

Stations on unregulated streams provide important information for monitoring hydrologic responses to climatic and land-use changes and for other hydrologic investigations that require unaltered flow information.

Table 3. Observation wells in Massachusetts and Rhode Island included in the U.S. Geological Survey national Collection of Basic Records (CBR) observation-well network

Identi-fication number	Town and state	Period of record	Geologic Material
A1W 47	Barnstable, MA	1962–present	Sand and gravel
PTW 51	Pittsfield, MA	1963–present	Sand and gravel
XNW 13	Winchendon, MA	1939–present	Till
SNW 6	Kingston, RI	1947–present	Sand and gravel

State Interest

State environmental and water-management agencies in Massachusetts and Rhode Island support the monitoring network to aid in fulfilling their respective missions. State governments share many of the same interests as NSIP, but their interest also extends to drought analysis, watershed planning and management, water supply, and localized or stream-specific management or developmental issues. Suburban and urban development in Massachusetts and Rhode Island has placed demands on State agencies to monitor and manage water resources in basins stressed by urbanization, particularly the allocation of water resources to meet competing demands for water supply and environmental protection. The 1986 Massachusetts Water Management Act (2002) authorizes the MADEP to regulate the quantity of water withdrawn from surface- and ground-water supplies to ensure adequate water for current and future needs. When permitting new withdrawals and the reissuing of permits, the MADEP considers streamflow requirements to protect stream habitat and relies on data from the monitoring network to carry out this task.

The observation-well network provides essential information for the implementation of the Massachusetts Title 5 septic-system regulations (Massachusetts Department of Environmental Protection, 310 CMR 15.000, accessed July 17, 2002). In 1981, a technique was developed by the USGS to estimate high ground-water levels at a proposed septic-system site by comparing a one-time ground-water-level measurement at the proposed site to records at a nearby long-term observation well (Frimpter, 1981). In addition, observation-well, streamflow, and precipitation data are fundamental measures used by the States to evaluate drought conditions for deciding whether to issue drought warnings to ensure adequate public-water supplies.

The Massachusetts Water Resources Authority (MWRA), along with the Massachusetts Metropolitan District Commission Division of Watershed Management (MDC–DWM), is responsible for managing and protecting drinking-water supplies for more than 2 million residents in the Boston area. The MWRA and MDC–DWM funds the operation of eight streamgage stations to monitor flows into and out of the Quabbin and Wachusett Reservoirs (primary supplies) and the Sudbury Reservoir (back-up supply). The MDC, through its Division of Parks, Engineering, and Construction, funds the operation of six streamgages in the Charles River, Mystic River, and Boston Harbor Basins primarily for flood protection for the City of Boston and nearby suburbs.

The RIDEM, RIWRB, and the PWSB support the monitoring network in Rhode Island to help them meet their responsibilities for water-resource management and protection. The RIDEM funds eight streamflow stations, most of which are in northern Rhode Island. The RIWRB funds nine streamflow stations, most of which are in southern Rhode Island. The PWSB funds one streamflow station in central Rhode Island, on a tributary to the Scituate Reservoir, the State's principal water supply. RIDEM and the RIWRB equally support the observation-well network to help them evaluate sustainability of ground-water supplies and for estimating high ground-water-level measurements at proposed septic sites (Socolow and others, 1994).

Other Interest

Interest in streamflows and ground-water levels comes from a wide range of entities that include local government agencies, conservation commissions, watershed associations, consultants, academic research and teaching, developers and construction companies, owners of small hydro-electric dams, anglers, boaters, and private citizens. The MADEM and MADEP, under the direction of the EOEA, enacted the Massachusetts Watershed Initiative in 1995 (Executive Office of Environmental Affairs, accessed July 17, 2002) to address water-resources issues for localized river basins. Watershed Teams comprised of Federal and State agencies and community partners (non-profit organizations, municipal boards, and businesses) were formed to monitor water resources and develop protection strategies for each of the 27 major river basins in Massachusetts.

Whitewater rafting on the Deerfield River in western Massachusetts (photo courtesy of Zoar Outdoor).

An example of a local use of streamflow data is the commercial white-water rafting industry. These companies provide white-water adventures for about 25,000 people annually on the Deerfield, Millers, and Westfield Rivers. Discharge information provided by stations on these rivers is routinely used by white-water outfitters to determine whether there is sufficient flow in the Millers and Westfield Rivers, and to evaluate high-flow conditions. High-flow conditions are used to determine the class of the rapids, the size of the raft needed, and the ability and comfort level of their customers to run these rivers safely (Bruce Lessels, Zoar Outdoor, written commun., 2001).

Additional hydrologic-monitoring needs were assessed by a survey that was sent to EOEA Watershed Team Leaders and current cooperators. The survey asked participants to list additional stream-monitoring needs and their uses of existing station data. Thirty-three questionnaires were sent out and, of the responses received (about half), most indicated a need to obtain additional streamflow data in coastal streams with drainage basins under 25 mi^2 (table 4). Flow data from most of these stations are needed for regional hydrologic information, protection of anadromous fish, and water-supply regulation. In western Massachusetts, one discontinued station was recommended for reactivation to provide minimum-flow information, additional flood-warning capabilities, and monitoring below a hydroelectric facility.

Discharge measurements during winter conditions are especially important to define changes in the stage-discharge relation. A flow meter is lowered through holes drilled in the ice to measure discharge on the South River near Conway, Massachusetts (station number—01169900).

Table 4. Additional streamgage stations identified in a monitoring needs assessment survey

[FERC, Federal Energy Regulatory Commission]

Basin	Stream	Reason station is needed
Housatonic	West Branch Housatonic River	Watershed, stormwater, and lake management
Deerfield	Deerfield River near Rowe	Minimum flow information, flood warning, and FERC verification
	Clesson Brook	Regional hydrologic information and habitat protection
	Chickly Brook	Regional hydrologic information and habitat protection
	Cold Brook	Regional hydrologic information and habitat protection
Merrimack	Merrimack River	Flow between Lowell and Newburyport
Parker	Parker River at Georgetown	Regional hydrologic information and minimum flows for habitat protection
Ipswich	Maple Meadow Brook	Regional hydrologic information and minimum flows for habitat protection
	Ipswich River at Martins Brook	Regional hydrologic information and minimum flows for habitat protection
North Coastal	Small Pox Brook near Route 1 Salisbury	Support for reintroduction of anadromous fish
Cape Cod	Herring River near Harwich	Reactivate discontinued streamgage station (01105880) for minimum flow information
	Mashpee River near Mashpee	Regional hydrologic information and habitat protection (anadromous fish)
	Herring River near Wellfleet	Regional hydrologic information and habitat protection (anadromous fish). Replace rated staff gage
Buzzards Bay	Canoe River	Water-supply regulation
	Mill River	Water-supply regulation
Pawcatuck	Queen River at Route 2	Regional hydrologic information and water supply

TRENDS IN THE NETWORK

The first continuous streamgage station (01170500) in Massachusetts began operation in 1904 on the Connecticut River at Sunderland (moved to Montague City in 1929). During the early part of the century, a few stations were added to the network in Massachusetts each year until World War I (1916), when the number of stations leveled off at about 16 sites through the late 1920s (fig. 3). The first continuous streamgage station in Rhode Island began operating in 1915 on the Pawtuxet River at Fiskeville, but was discontinued 10 years later (fig. 3). Continuous streamgaging activity did not resume in Rhode Island until 1929 when the station on the Blackstone River at Woonsocket (01112500) began operation.

Stations were gradually added to the network in Massachusetts through the late 1930s. Severe flooding in 1936 and 1938 (Wandle and Lautzenheiser, 1991) prompted a marked increase in the number of stations during the late 1930s and early 1940s in Massachusetts and Rhode Island. The rate at which stations were added to the network was lower throughout the next 20 years until 1962, when a study began in cooperation with the Massachusetts Department of Public Works and the Federal Highway Administration to define streamflow characteristics of small rural streams (Wandle, 1983). About 30 sites were added to the network, mostly on streams with drainage areas of less than 10 mi^2, for peak-flow studies of small rural watersheds (Wandle, 1983). The total number of stations in Massachusetts and Rhode Island peaked at 114 in 1973 before most of the flood-study stations were discontinued.

After the early 1970s, the number of stations in Massachusetts steadily decreased through the early 1990s. In 1990, discharge records were no longer published at nine stations below flood-control dams operated in cooperation with the ACOE (not reflected in fig. 3). Although these stations are still operated for flood-control purposes, discharge records at these sites are not readily available because formal computation of the data, including estimating missing and erroneous records, is not routinely done. The number of stations in Massachusetts has increased in recent years because the MADEP, in the course of issuing water-management and water-withdrawal permits, has required those seeking permits to establish streamflow-monitoring stations to protect wildlife habitat and fisheries and to protect the natural integrity of rivers.

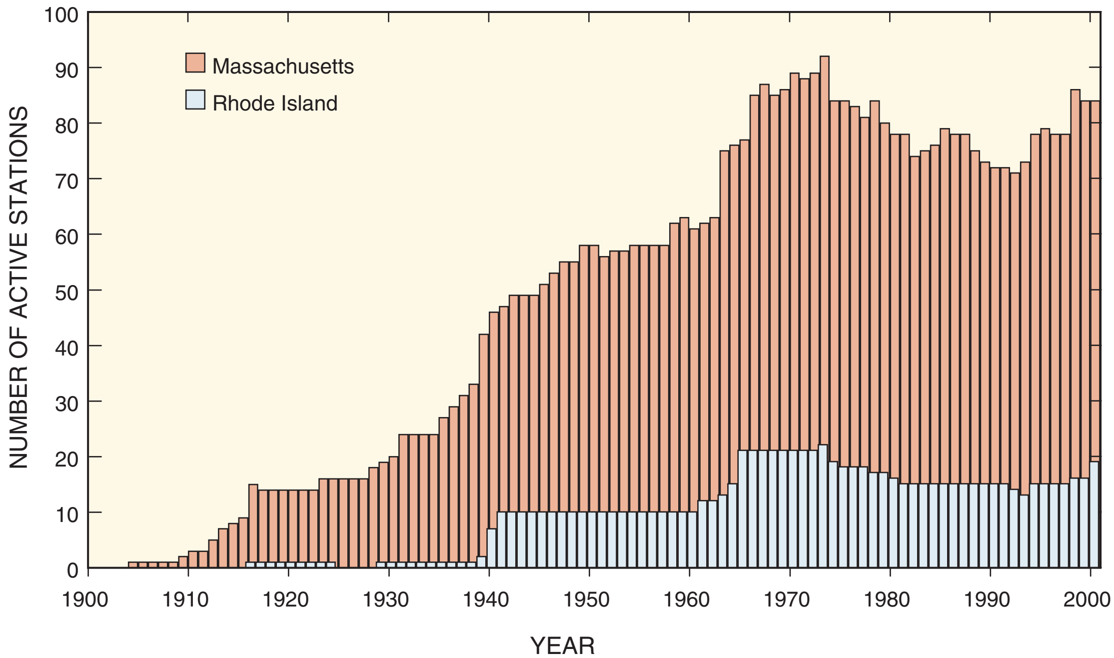

Figure 3. Number of continuous streamgage stations reported annually by the U.S. Geological Survey in Massachusetts and Rhode Island, 1900 to 2000.

Figure 3 includes all stations that were operated during each water year; this count includes stations operated for specific short-term research needs. Although these stations provide data for current research or water-resource investigations, they are typically operated for relatively short periods dictated by the requirements of a particular project; thus, they do not provide the long-term streamflow records needed for many hydrologic investigations. Of the 76 stations that have been discontinued in Massachusetts, 59 percent of these stations have less than 10 years of record, 20 percent have between 10 and 20 years of record, and 21 percent have more than 20 years of record. Of the 14 stations that have been discontinued in Rhode Island, 36 percent of these stations have less than 10 years of record, 57 percent have between 10 and 20 years of record, and 7 percent have more than 20 years of record.

Systematic observation-well measurements began in Massachusetts at Topsfield in 1936 and in Rhode Island at Providence in 1944. The number of observation wells in Massachusetts increased slowly until the early1960s, when about 50 wells were added to the network in a short time during and following the most severe drought of record (fig. 4). The number of observation wells in Massachusetts increased sharply again in the 1970s with the addition of 51 wells to the network on Cape Cod and the Islands. These observation wells were added to improve evaluation of water supplies and the effects of development pressure on sole-source aquifers. In Rhode Island, the number of observation wells increased slowly but steadily from the 1940s to the 1990s, when the number of wells nearly doubled because of a desire by the RIDEM to better represent ground-water levels in till.

Modernization of Streamflow Monitoring

The basic method for measuring streamflow by recording stream stage and relating the stage to flow by a stage-discharge relation has remained unchanged since the late 1800s, when streamgaging first began in this country. The equipment used to measure, record, and process streamflow data has changed considerably since that time, however. The earliest recording devices were graph-paper recorders that traced stream stage with time. A pen linked to a float suspended in a stilling well continuously traced stage on a paper chart that advanced by a mechanical clock driven by a weight. Hydrographers read the paper charts, made corrections to the time, or stage, or both, and converted the stage reading to a discharge from a stage-discharge rating developed from

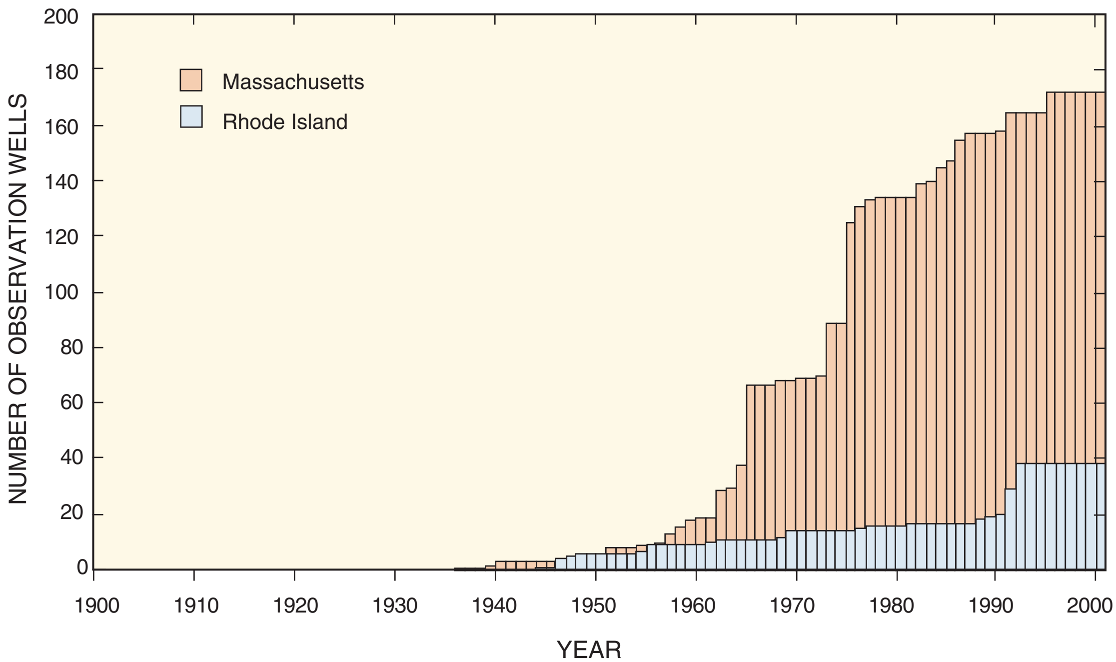

Figure 4. Number of observation well records reported annually by the U.S. Geological Survey in Massachusetts and Rhode Island, 1900 to 2000.

periodic streamflow measurements. In the early 1960s, recorders that punched stage readings into paper tapes at set time intervals gradually replaced this technology. Punched tapes allowed the automated processing of stage readings into electronic files, and thus ushered in the era of digital record processing. Mercury manometers (bubble gages) were developed about this time as an alternative to float-tape gages. Some stations were telemetered by synchronizing remote recorders with a transmitter or by phone-line dial-up impulse recorders (telemark gages). Modern stream-measuring technology evolved rapidly in the 1980s and 1990s with electronic stage sensors and recorders. Electronic recorders and sensors progressively replaced older equipment; and by 1994, all streamgage stations in Massachusetts and Rhode Island had been equiped with electronic recorders.

Current streamgaging equipment has improved the reliability of measurements; missing data have decreased from an average of about 5 percent per year when non-digital recorders were used to less than one percent per year at present. Electronic recording and processing have also vastly improved the dissemination of data. By the end of the 2001 water year, about 70 percent of all streamgage stations in Massachusetts and Rhode Island were

Digital recorder compiles flow meter readings and computes discharge measurements.

equipped with digital collection platforms (DCPs) that transmit data by satellite every 4 hours. Twenty-one of these stations are also equipped with precipitation recorders to allow near real-time transmission of streamflow and precipitation data. Data is downlinked to computers and stored in the NWIS database. These computers are networked within the USGS, and the data in NWIS is available to any user connected to the Internet (http://water.usgs.gov). In addition, many streamgage stations are equipped with telephone modems that allow transmission of real-time data (DCPs depend on the correct position of the satellite to transmit data, but are not affected by phone lines that could be down during severe storms).

The MA–RI District has made limited use of Acoustic Doppler Current Profiler (ADCP) technology to measure streamflow. The ADCP continuously measures water velocity and depth as it moves across the stream channel (Morlock and others, 2002). An ADCP was used to measure discharge in the Connecticut River during high flow because conventional boat measurements were not possible.

Data collected at stations have traditionally been published as a mean daily discharge printed in an annual data report. The widespread use of the Internet has enabled the USGS to provide streamflow, water-quality, and ground-water data on demand. Data available through the Internet include all historical mean daily streamflow records in addition to data collected as recently as the last hour. The NWIS database also contains unit-value discharge records for the 1988 water year, and from the 1990 water year to present; these are values that the streamgage records, typically at 15- or 60-minute intervals. Prior to this, only mean daily discharge values were saved electronically because of storage limitations. In addition, applications have been developed that allow users to view data in a variety of ways. As a result, the need to publish paper copies of the annual data report has diminished, and it is anticipated that printed copies of these reports will not be widely produced after the 2003 water year.

Streamgage station and precipitation gage on Hobbs Brook below the Cambridge Reservoir near Kendall Green, Massachusetts (station number—01104430).

Modernization of Ground-Water-Level Monitoring

Ground-water observation wells were traditionally measured manually at monthly intervals. These measurements were made by lowering a chalked steel tape to determine the depth to water. A problem with these infrequent measurements is that they may not provide enough information for the interpretation of ground-water-level changes in response to recharge, pumping, or surface-water interaction. The importance of the frequency of measurements is described by Taylor and Alley (2002).

In response to this need, streamflow-measuring equipment was adapted to provide continuous water-level records to delineate changes at short, regular intervals in observation wells. The types of ground-water recording equipment evolved as streamflow-monitoring equipment changed—from paper chart recorders, to paper punch tapes, to digital records, and DCPs that transmit data in near real time.

In 2001, the MADEP provided funding for a one-time capital improvement to upgrade four of the six recording wells and install DCPs in wells that were measured monthly. The benefits of real-time ground-water data are described by Cunningham (2001); these benefits include providing detailed and immediate ground-water-level data, improved data quality by minimizing equipment malfunctions, and potential operational cost savings. The ROBOWELL, an integrated ground-water-level and water-quality monitoring system, was developed by Granato and Smith (2002) to monitor sites where rapid changes in ground-water quality can occur. One ROBOWELL is currently used in the observation-well network in Truro, Mass., to monitor the position of the freshwater/saltwater interface in a water-supply well field.

Observation well equipped for continuous recording and satellite telemetry of ground-water-level data near Acton, Massachusetts (ACW 158).

CORRELATED STREAMGAGE STATIONS

Stations that are well correlated can often be used to estimate discharge records affected by equipment malfunctions, ice, or other causes. HYDCOMP, a Statistical Analysis System (SAS) macro, was developed to search the ADAPS daily-value records for the five best correlated stations (Curtis Sanders, U.S. Geological Survey, written commun., 2002). For each station, HYDCOMP regresses the log of the daily discharge values between two stations; independent station values are also lagged forward and backward from one to eight days from the dependent station values during the regression procedure. The five most correlated stations (index stations) are ranked from the lowest standard error of estimate and the highest correlation coefficient (r^2) values.

Correlations determined by HYDCOMP may identify index stations not previously considered in estimating missing records at a station and, if several stations are in physiographically similar areas and nearby one another, the list can be used to determine which ones are best correlated. HYDCOMP results should not be the sole basis for selecting index stations, however, because these stations could be in areas which are physiographically, climatically, or hydrologically dissimilar. Distant stations could be highly correlated strictly by chance; therefore, judgment is required to evaluate the goodness-of-fit with other criteria in identifying index stations.

Index stations were selected by HYDCOMP for most stations by using discharge records between April 1st and November 30th for the 1997 through 2001 water years. Eighteen stations were not included in this analysis: Merrimack River at Lowell, MA (01100000); Connecticut River at Montague City, MA, and at Holyoke, MA (01170500 and 01172003); Quashnet River at Waquoit Village, MA (011058837); Mother Brook at Dedham, MA (01104000); Town Brook at Quincy, MA, (01105585); and nine stations below reservoirs operated by the ACOE that have unpublished records (West River below West Hill Dam near Uxbridge, MA, 01111200; Quinebaug River below East Brimfield Dam near Fiskdale, MA, 01123360; Quinebaug River below Westville Dam near Southbridge, MA, 01123600; French River below Hodges Village Dam at Hodges Village, MA, 01124350; Little River near Oxford, MA, 01124500; French River at Webster, MA, 01125000; Millers River at South Royalston, MA, 01164000; East Branch Tully River near Athol, MA, 01165000; and Middle Branch Westfield River at Goss Heights, MA, 01180500), and three stations with less than 2 years of record or more than 30 days of missing record (Mill River near Rockport, MA, 01102029; Sawmill River near Rockport, MA, 011020308; and Charles River above Watertown Dam at Watertown, MA, 01104615). In general, most stations were paired with one or more highly correlated index stations. Correlated stations had a median-root-mean square error of 30 percent and lower and upper quartile ranges of 23 and 41 percent, respectively. The median correlation coefficient (r^2) was 92.8 percent and the lower and upper quartiles ranged from 88.9 to 94.5 percent. Index stations and their correlation statistics are listed in Appendix 2.

STREAMGAGE-STATION METRICS

Streamgage stations were evaluated for various measures that affect potential uses of the data. These metrics include record length, effects of regulation, distribution by physiographic region, drainage-basin size, physical basin characteristics, and combinations of these factors. These metrics do not provide an exhaustive measure of all factors that might be considered in evaluating the network; rather, they provide a general understanding of the types of basins represented and some of the limiting factors of the network. Summaries of various metrics are provided in the following section and information on these metrics can be found for individual stations in Appendix 1.

Record Length

Besides the need to know present flow conditions, streamflow data from stations operated continuously over many years enable the analysis of the magnitudes and expected recurrence intervals of flood flows and low flows, evaluation of trends in hydrologic conditions associated with changing land use such as increased peak flow and decreased base flow, and the development of relations between physical basin characteristics and flow. Most stations (active during the 2000 water year and discontinued) have less than 5 years of record or more than 50 years of record (fig. 5*A*). If the discontinued stations are excluded, about 55 percent of the stations active during the 2000 water year have more than 50 years of record (fig. 5*B*). This indicates that most discontinued stations were operated for 5 years or less, which reflects the short-term nature of the hydrologic investigations for which they were used.

The record lengths of active stations (during the 2000 water year) provide a better indication of the continuity of the network. In Massachusetts, 74 percent of the active stations have 30 or more years of record; in Rhode Island 52 percent of the active stations have 30 or more years of record. Collectively, 71 percent of the active stations in Massachusetts and Rhode Island have 30 or more years of record and most of these have more than 50 years of record. Record lengths of 30 or more years are considered most appropriate for analysis of hydrologic trends and flow-frequency analysis. Although

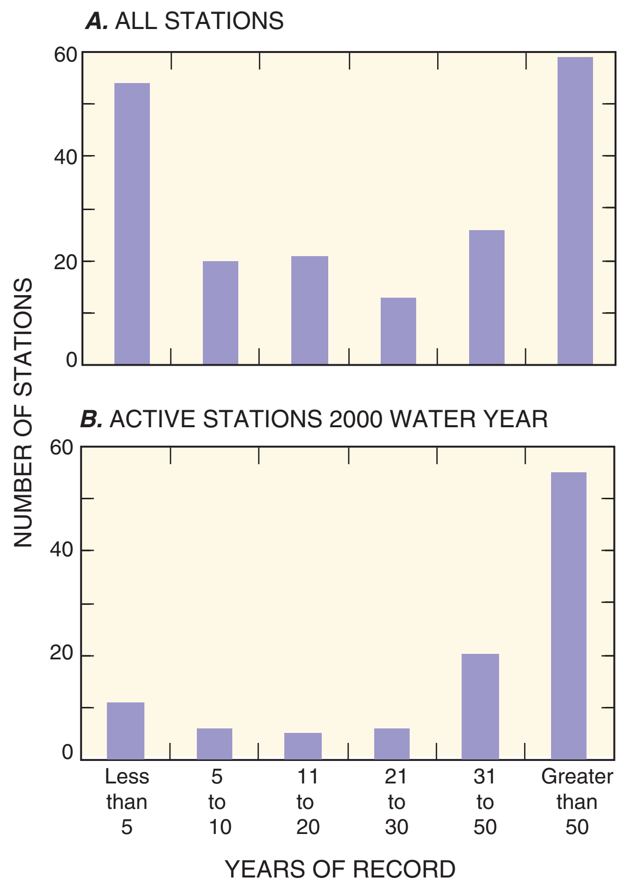

Figure 5. Record length of U.S. Geological Survey streamgage stations operated in Massachusetts and Rhode Island: (*A*) all stations (includes discontinued stations), and (*B*) stations active during the 2000 water year.

Massachusetts and Rhode Island are fortunate to have a high percentage of stations with long lengths of record, other factors need to be considered in the evaluation of the station record. For example, are records affected by regulation and do the stations represent a cross section of physiographic regions and basin characteristics?

Regulation

Regulation of flow upstream of a streamgage station can affect the potential use of its data. For example, flood-control reservoirs will likely dampen peak flows relative to a similar site without regulation; thus, data collected at a site downstream of a flood control reservoir would not be useful in a regional peak-flow study, but depending on how the reservoir storage is managed, the data could be used for other purposes. For example, a flood control reservoir that is normally empty except for the water that passes through it could still be useful in an analysis of low flows. Forms of regulation include water withdrawals, discharges from wastewater-treatment facilities, diversions, and controlled releases of reservoir storage. Regulation can also be caused by natural influences such as beaver activity or tidal fluctuations. Few, if any, streams and rivers in Massachusetts and Rhode Island are completely free of regulation; nevertheless, the extent to which regulation influences flow has been assessed for each gaging station. Each station was assigned to one of five classes of regulation: (1) minimally affected or not affected, (2) affected only at low flows, (3) affected only at high flows, (4) affected at all flows, and (5) effects are variable, such as a tidal fluctuation. These assignments were determined on the basis of remarks published in the annual data report (for example, Socolow and others, 2001).

About 21 percent of stations in Massachusetts and 43 percent of stations in Rhode Island active in the 2000 water year are considered unaffected, or minimally affected, by regulation. In Massachusetts, active stations are affected by regulation at low flows at 28 percent of stations, at all flows at 44 percent of stations, at variable flow at 6 percent of stations, and at high flows at 1 percent of stations. In Rhode Island, active streamflow stations are affected by regulation at low flows at 38 percent of stations, all flows at 14 percent of stations, and variable flow at 5 percent of stations (fig. 6).

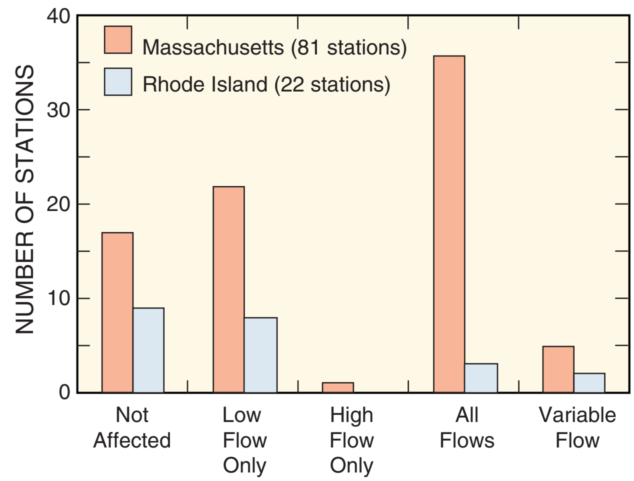

Figure 6. Number of streamgage stations in Massachusetts and Rhode Island affected by regulation, 2000 water year.

Physiographic Region

The hydrologic variability associated with different physiographic regions can be an important consideration in hydrologic analysis. Denny (1982) described seven physiographic regions in Massachusetts and Rhode Island; from east to west, these are the Coastal Plain, Coastal Lowlands, Central Highlands, Connecticut Valley, Hudson Green-Notre Dame Highlands, Vermont Valley, and the Taconic Highlands (fig. 7). For this evaluation, the physiographic regions described by Denny were simplified into three regions—Coastal Lowlands, Central Uplands, and the Western Highlands. Stations were assigned to the region that includes most of their drainage area. Stations on the Connecticut and Merrimack Rivers were not assigned to a physiographic region because these stations have large drainage basins, which are not representative of any one region.

The Coastal Lowlands include the Coastal Plain and Coastal Lowlands regions described by Denny (1982) and include part or all of the Nashua, Boston Harbor, Charles, Concord, Ipswich, Shawsheen, North Coastal, Parker, South Coastal, Buzzards Bay, Taunton, and Cape Cod and Islands drainage basins in Massachusetts, and part or all of the Narragansett Bay, Ten Mile, Woonasquatucket, Moshassuck, Blackstone, and the Pawcatuck drainage basins in Rhode Island. The Central Uplands includes stations with drainage basins in the Connecticut Valley region east of the Connecticut River. Basins in the Central Uplands include part or all of the Chicopee, Millers, Nashua, Quinebaug, French, and Blackstone drainage basins in Massachusetts, and the Pawtuxet, and Hunt drainage basins in Rhode Island. The Western Highlands, to the west of the Connecticut River, includes part or all of the Deerfield, Farmington, Housatonic, Hudson, and Westfield drainage basins.

Most of the active stations in Massachusetts and Rhode Island have drainage basins in the Coastal Lowlands (48 and 77 percent, respectively). Stations with drainage basins in the Central Uplands represent 35 and 23 percent of the active stations in Massachusetts and Rhode Island, respectively (fig. 8). In Massachusetts, 12 percent of the active stations have drainage basins in the Western Highlands and about 5 percent were not assigned to a physiographic region. Normalized for area, the density of stations with drainage areas in the Coastal Lowlands and the Central Uplands regions is similar (about one station for every 100 mi^2), but the density of stations is about half this value in the Western Highland region.

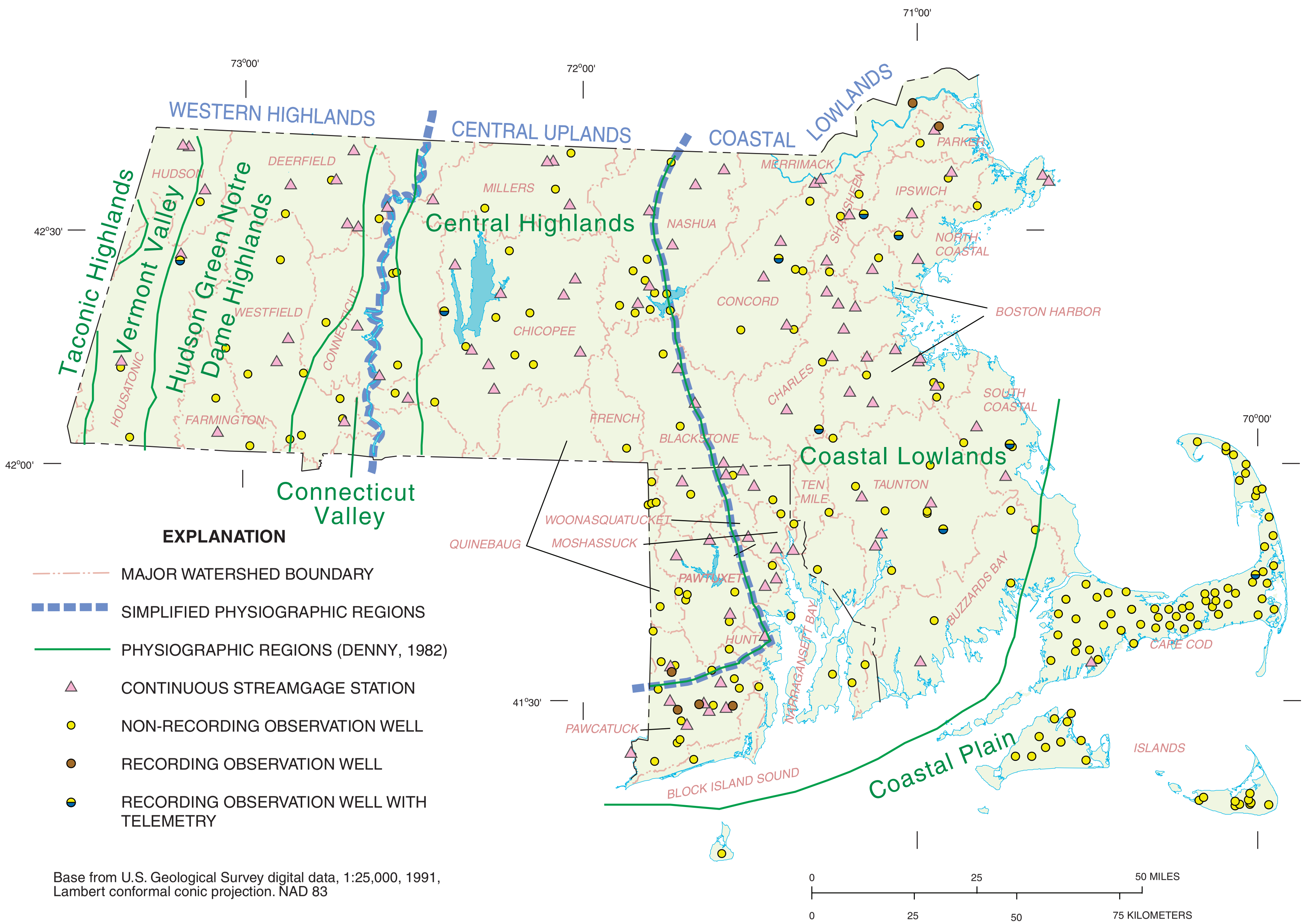

Figure 7. Physiographic regions, major river basins, and the U.S. Geological Survey streamflow station and observation-well network in Massachusetts and Rhode Island, 2000 water year.

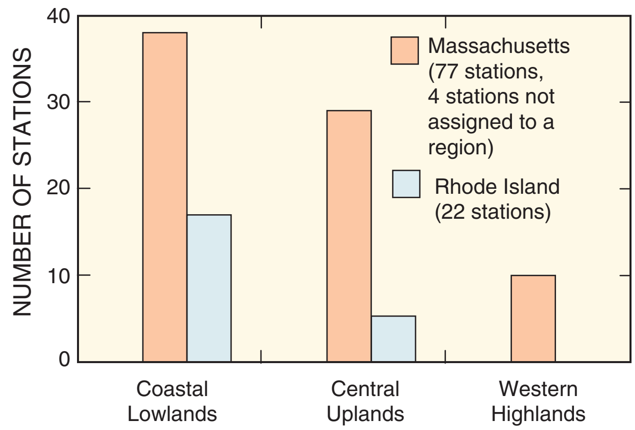

Figure 8. Distribution of U.S. Geological Survey streamgage stations in Massachusetts and Rhode Island by physiographic region, 2000 water year.

Basin Characteristics

The basin characteristics associated with streamgage stations include mean basin slope, mean basin elevation, stream-channel length, land cover (percent of basin cover as water, wetlands, forest, urban areas) and the percent of the basin area underlain by sand and gravel. Basin characteristics, other than drainage-area size, were not determined for five stations in Massachusetts: Merrimack River at Lowell (01100000), Connecticut River at Montague City and at Holyoke (01170500 and 01172003), Quashnet River at Waquoit Village (011058837), and Mother Brook at Dedham (01104000). Basin characteristics were not determined for these sites. The Merrimack and Connecticut River stations drain areas of 4,400 mi^2 or more, and Mother Brook is a diversion channel between the Charles and Neponset Rivers. Basin features for these streamgage stations were not considered particularly relevant. The basin characteristics for the Quashnet River are not included in the summary characteristics because its ground-water and surface-water drainage areas differ; basin characteristics, however, are given for each in Appendix 1. As part of this analysis, the drainage area for each station (except for the Connecticut, and Merrimack River stations) was digitized to provide a standard basin-boundary reference for future applications.

Basin slope and elevation were determined from 1:24,000-scale National Elevation Data (U.S. Geological Survey, accessed July 17, 2002). Channel length was determined from 1:24,000 or 1:100,000-scale hydrology digital line graph (DLG) data. Land-cover features were determined mostly from MassGIS (Massachusetts Geographic Information System, accessed July 17, 2002) and RIGIS (Rhode Island Geographic Information System, accessed July 17, 2002) digital land-use/land-cover maps, which generally reflect conditions of the early 1990s. Drainage areas outside of Massachusetts and Rhode Island were compiled from digital land-use/land-cover (LULC) maps from neighboring states by using 30-m National Land Cover Data (NLCD) described by Vogelmann and others (2001). All LULC maps were converted to NLCD classification and scale. Urban areas include LULC cover classified as high-intensity residential development, commercial, industrial, and transportation. Forest areas include LULC cover classified as deciduous, evergreen, and mixed forest. Agriculture areas include LULC cover classified as orchards, vineyards, pasture, and row crops. Other areas include LULC cover classified as low-intensity residential, quarries, gravel pits, bare rock and sand, shrub lands, and open urban. Basin characteristics are summarized for 98 stations in box plots (fig. 9) and are presented for individual stations in tables in Appendix 1.

Physical Characteristics

Drainage-basin size is typically the single most important explanatory variable in streamflow-estimation techniques. Therefore, regional analysis should include stations that represent a wide range of drainage-basin sizes. In Massachusetts, gaged basins ranged in size from 0.39 to 8,309 mi^2, with a median of 60 mi^2. In Rhode Island, gaged basins ranged in size from 3.55 to 417 mi^2, with a median size of 54 mi^2.

Stations with drainage areas under 10 mi^2 represent about 10 percent of the stations in Massachusetts and about 23 percent of the stations in Rhode Island (fig. 10*A*). Drainage areas between 10 and 100 mi^2 represent about 55 percent of the stations in Massachusetts and 64 percent of the stations in Rhode Island. About 22 percent of the stations in Massachusetts have drainage areas between 100 and 300 mi^2, and about 13 percent of the stations have drainage areas greater than 300 mi^2. In Rhode Island, only three stations have drainage areas greater than 100 mi^2 (none more than 500 mi^2). In general, the current streamflow-monitoring network represents a broad range of drainage-basin sizes.

About 60 percent of the discontinued stations in Massachusetts and about 70 percent of the discontinued stations in Rhode Island have drainage areas less than 10 mi^2 (fig. 10*B*). The high proportion of discontinued stations with drainage areas less than 10 mi^2 reflects the project-specific stations operated during the 1970s to estimate peak flows on small streams (Wandle, 1983).

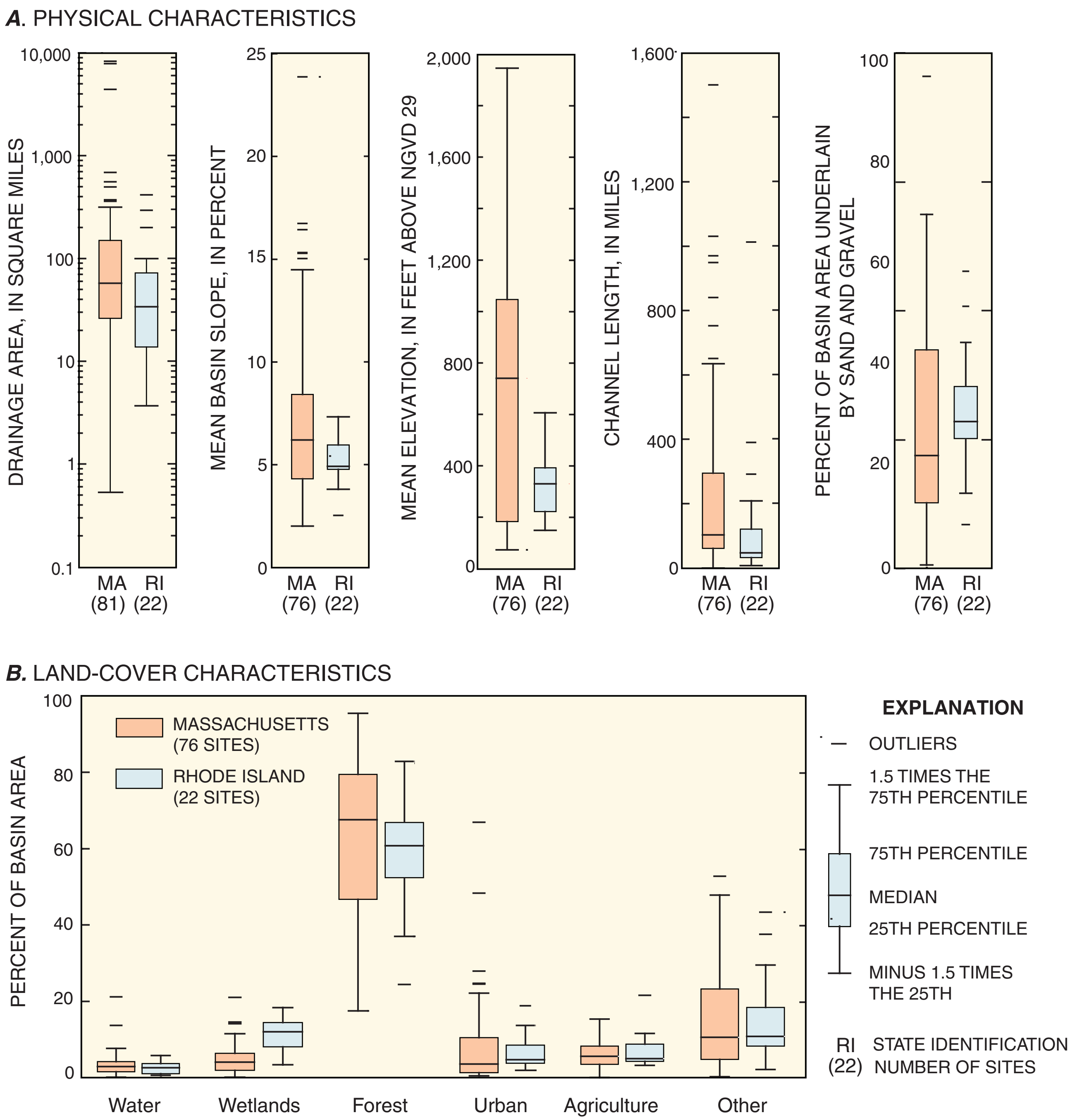

Figure 9. Summary of selected basin characteristics upstream of active U.S. Geological Survey streamgage stations in Massachusetts and Rhode Island, 2000 water year: (*A*) physical characteristics, and (*B*) land-cover characteristics.

In Massachusetts, the mean basin slope ranged from about 2 to 24 percent with a median of 6.2 percent (fig. 9*A*). In Rhode Island, the mean basin slope ranged from 2.5 to 7.3 percent with a median of 4.9 percent. The mean basin slope for stations in the Western Highlands (median of 12.1 percent) was about twice that of the Central Uplands (median of 7.3 percent) and Coastal Lowlands (median of 4.7 percent). Similarly, the mean basin elevation was greatest for stations in the Western Highlands (median of 1,460 ft) and lowest for stations in the Coastal Lowlands (median of 211 ft). Stations that drain the Central Uplands had a median mean basin elevation of 885 ft. The median of the mean basin elevation for all stations in Massachusetts and Rhode

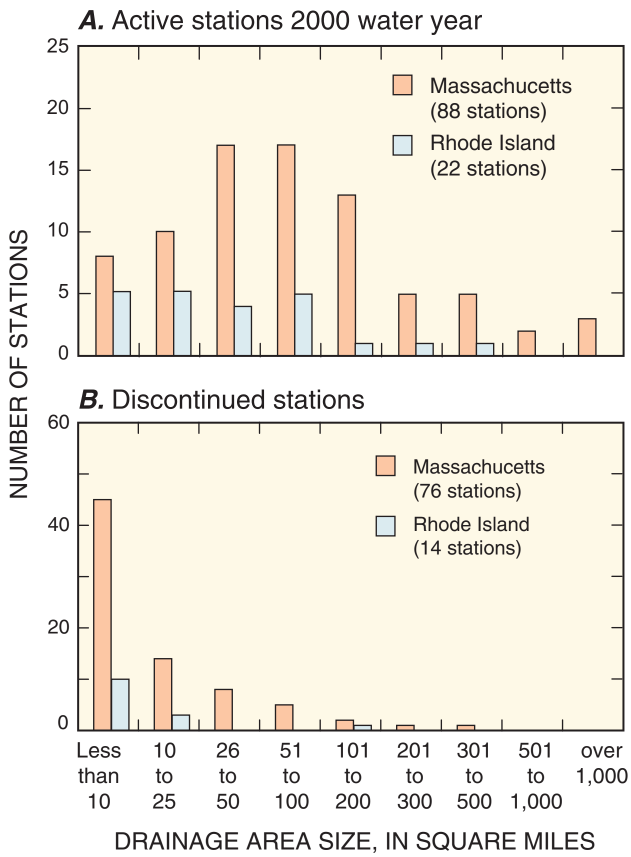

Figure 10. Number of U.S. Geological Survey streamgage stations in Massachusetts and Rhode Island by drainage-area size for (*A*) active stations during the 2000 water year, and (*B*) discontinued stations.

Island was 462 ft; the median elevation for Massachusetts basins (744 ft) was about twice that for Rhode Island basins (354 ft). The median channel length for Massachusetts stations (103 mi) was about twice that for Rhode Island stations (47 mi).

The percentage of the basin area underlain by sand and gravel is greatest in Coastal Lowland basins in Massachusetts (median of 42 percent of the basin area) and least in the Western Highlands (median of 11 percent of the basin area). In the Central Uplands, a median of 18 percent of the basin area was underlain by sand and gravel (fig. 9*A*). The areas underlain by sand and gravel were about the same for Rhode Island basins in the Coastal Lowlands and in the Central Uplands (29 and 25 percent of the basin area, respectively).

Land-Cover Characteristics

Land-cover characteristics indicate that gaged basins in Massachusetts and Rhode Island are mostly forested (median of 65 percent forest cover), but forest range from as little as 18 percent to as much as 95 percent of the basin area. Generally, basins are more forested in the Central Uplands (median 78 percent) and Western Highlands (median 81 percent) than in the Coastal Lowlands (median 52 percent). The Coastal Lowlands are generally more urbanized in Massachusetts (median of 10 percent) than in Rhode Island (median of 4 percent).

The percentage of gaged basin area classified as water, wetlands, and agriculture is generally small. The median basin area covered by water was 2.8 percent in Massachusetts and 2.5 percent in Rhode Island, but composed as much as 21 and 5.7 percent of the basin areas for Massachusetts and Rhode Island stations, respectively. The median basin area covered by wetlands was 3.9 percent in Massachusetts and 12 percent in Rhode Island, but composed as much as 21 and 18 percent of the basin area for Massachusetts and Rhode Island stations, respectively. The high percentage of wetland area in Rhode Island could be due, in part, to differences in the wetland covers from different sources. The median basin area in agriculture was 5.6 percent in Massachusetts and 5.0 percent in Rhode Island, but composed as much as 15 and 22 percent of the basin areas for Massachusetts and Rhode Island stations, respectively. Agricultural area tended to be slightly more prevalent in gaged basins in the Western Highlands (median of 7.6 percent) than in the other regions (median 5.2 percent). Land cover classified as "other" comprised about 12 percent of the basin areas in both Massachusetts and Rhode Island, and composed as much as 53 and 43 percent of the land cover in Massachusetts and Rhode Island basins, respectively.

Combined Metrics

Often, hydrologic analyses require streamflow data that satisfy multiple criteria. For example, development of regionalized equations that relate flow statistics to basin characteristics in STREAMSTATS (Ries and others, 2000) required stations with long records (generally 30 years or more), minimal regulation, and a wide variety of basin characteristics. Several of the metrics above were evaluated in combination to assess the distribution of stations with respect to multiple criteria commonly considered in hydrologic analyses.

Record length by region: Stations with record lengths of 10 years or less are mostly in the Coastal Lowlands, which reflects the introduction of these stations in recent years to monitor stressed basins (fig. 11). Stations with long-term records (greater than 30 years) are about equally distributed in the Central Highlands and Coastal Lowlands.

Regulation by region: In Massachusetts, regulation affects about 70 percent of the stations in the Coastal Lowlands, about 82 percent of the stations in the Central Uplands, and about 90 percent of the stations in the Western Highlands. In Rhode Island, regulation affects about 65 percent of the stations in the Coastal Lowlands and about 40 percent of the stations in the Central Uplands. Overall, in Massachusetts and Rhode Island, regulation affects about 70 percent of the stations in the Coastal Lowlands, mostly under low-flow conditions and to a slightly lesser extent under all flow conditions, and about 76 percent of the stations in the Central Uplands, mostly under all flow conditions (fig. 12).

Drainage area by region: In general, the number of stations decline as the drainage area decreases in each region. In the Coastal Lowlands, stations represent all drainage area ranges in Massachusetts and Rhode Island (fig. 13). Stations with the largest drainage basins are in the Coastal Lowlands because these stations generally have the greatest available upstream area. Few stations exist in the Central Uplands of Rhode Island, but these stations have drainage areas that are about equally distributed across the ranges less than 100 mi^2. In Massachusetts, about 16 percent of the stations in the Central Uplands have drainage areas less than 25 mi^2. No active stations in the 2000 water year in the Western Highland region of Massachusetts have drainage areas less than 25 mi^2.

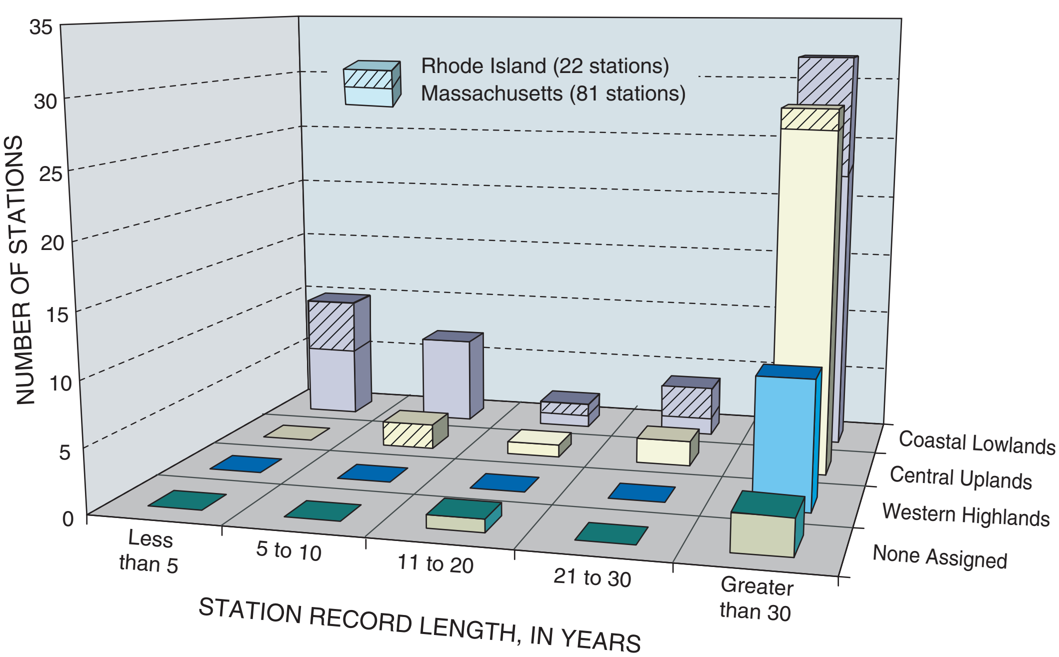

Figure 11. Number of active U.S. Geological Survey streamgage stations in Massachusetts and Rhode Island by physiographic region and years of record, 2000 water year.

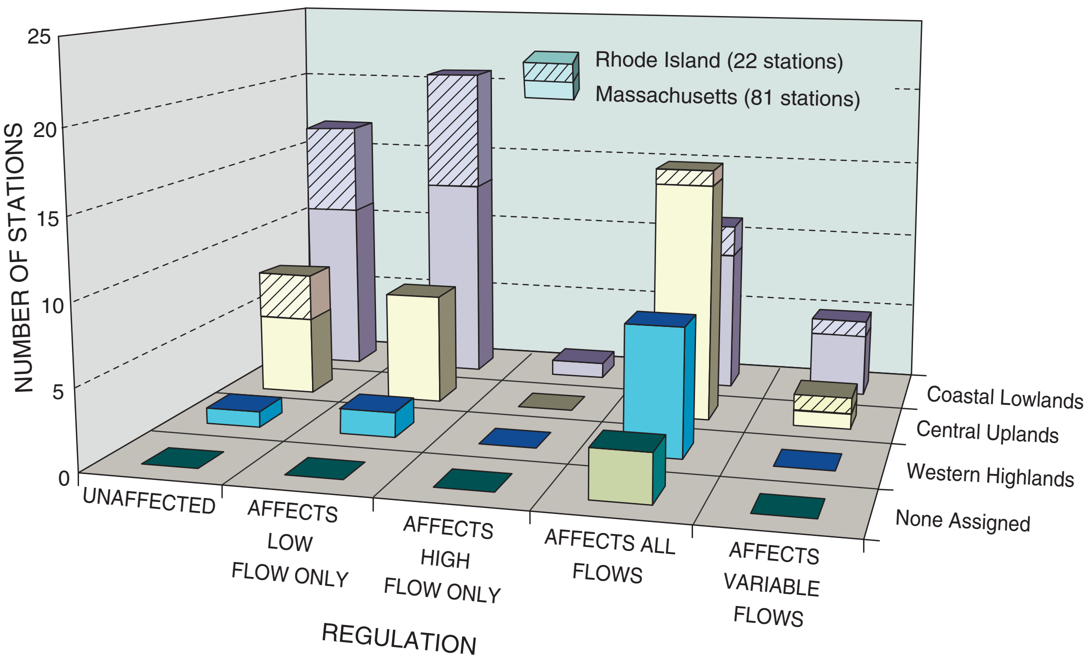

Figure 12. Number of active U.S. Geological Survey streamgage stations in Massachusetts and Rhode Island by physiographic region and regulation, 2000 water year.

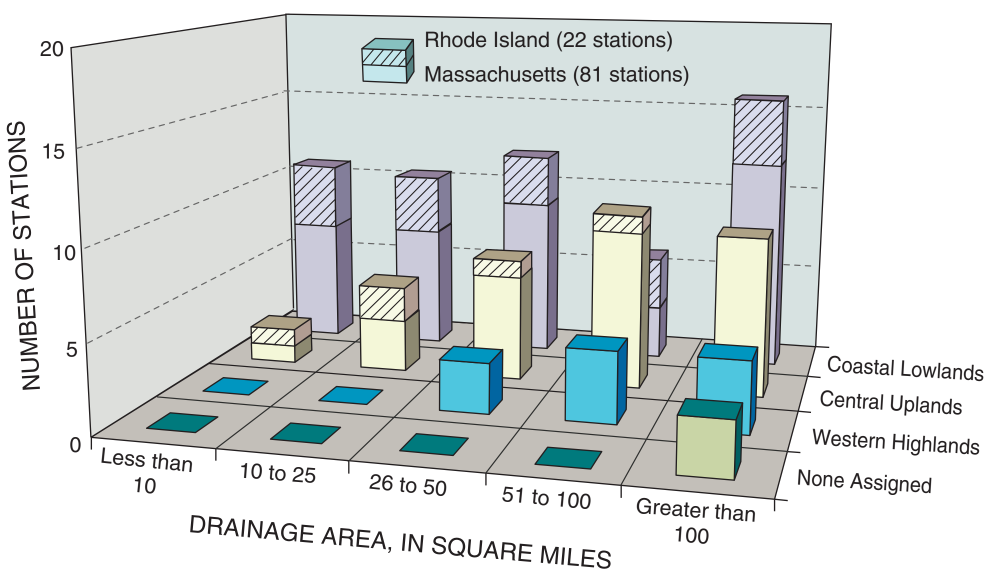

Figure 13. Number of active U.S. Geological Survey streamgage stations in Massachusetts and Rhode Island by drainage-area size and physiographic region, 2000 water year.

Regulation by record length: Massachusetts and Rhode Island stations with record lengths of 30 or more years are mostly affected by regulation (82 percent); about 50 percent of the stations are affected at all flows or variable flows, and about 32 percent of the stations are affected at low flows (fig. 14). Regulation affects 82 percent of Massachusetts stations with record lengths of 30 or more years; of these, about 52 percent are affected over all flows or variable flows, and about 30 percent are affected at low flows. Regulation affects about 83 percent of Rhode Island stations with record lengths of 30 or more years; of these, about 42 percent are affected over all flows or variable flows and about 41 percent are affected at low flow. About half of all stations with less than 10 years of record (52 percent) are affected by regulation; this percentage is less than the percentage of stations with long periods of record affected by regulation. Stations unaffected by regulation with less than 10 years of record represent about 9 percent of the stations in Massachusetts and Rhode Island, however. This underscores the importance of continuing the operation of stations unaffected by regulation for use in hydrologic analysis.

Record length by drainage area: Most stations in Massachusetts (74 percent) and about half of the stations in Rhode Island (54 percent) with drainage areas greater than 10 mi^2 have 30 or more years of record (fig. 15). Stations with drainage areas under 10 mi^2 are about equally distributed among the five record-length categories, but stations with the shortest record length (less than 5 years) are generally stations with the smallest drainage area.

Regulation by drainage-area size: The number of stations affected by regulation grouped by drainage area (fig. 16) indicate that nearly 93 percent of stations in Massachusetts with drainage basins larger than 100 mi^2 are affected by regulation; of these, 71 percent are affected at low flows. All four stations in Rhode Island with drainage areas greater than 100 mi^2 are affected by regulation. The number of stations affected by regulation over all flows in Massachusetts increases sharply as the drainage-area size increases. About 50 percent of all stations in Massachusetts and Rhode Island with areas less than 50 mi^2 are unaffected by regulation.

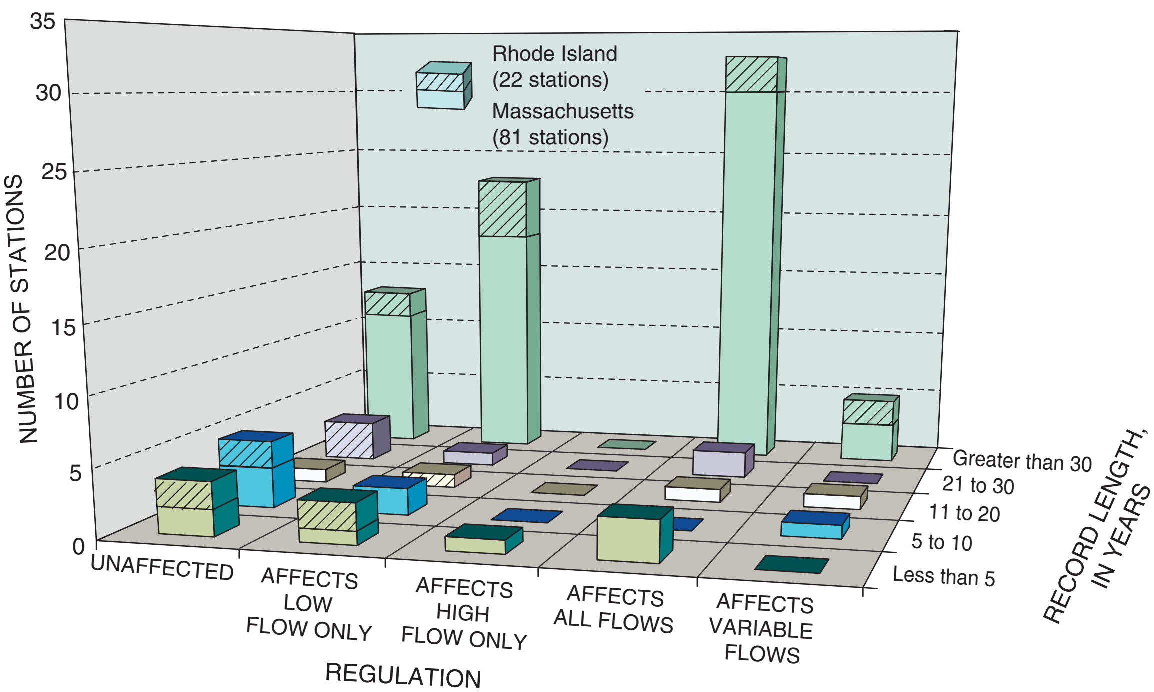

Figure 14. Number of active U.S. Geological Survey streamgage stations in Massachusetts and Rhode Island by regulation and record length, 2000 water year.

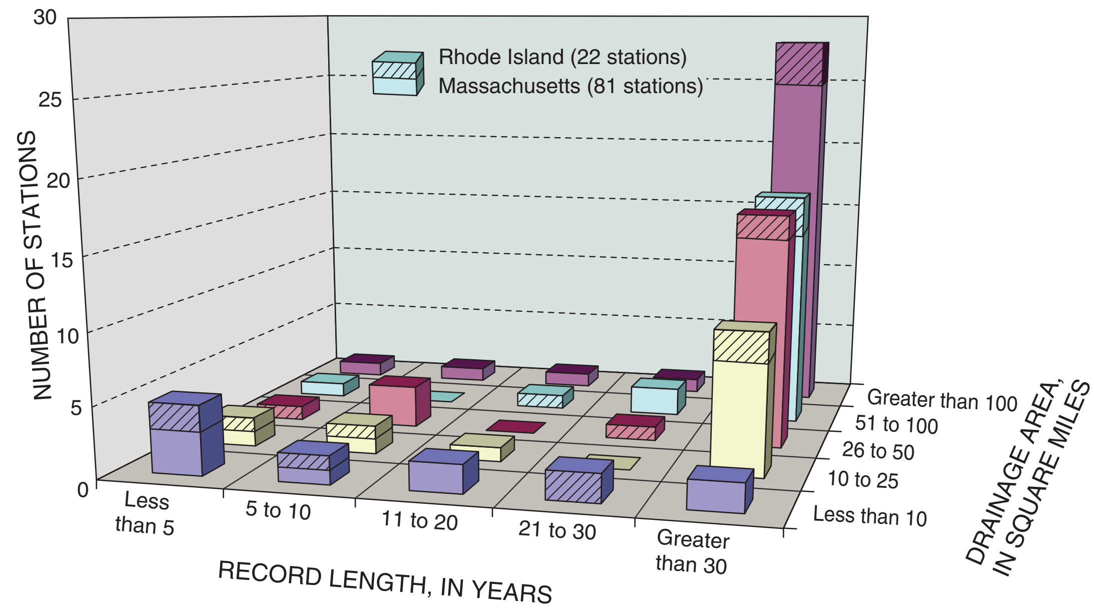

Figure 15. Number of active U.S. Geological Survey streamgage stations in Massachusetts and Rhode Island by record length and drainage-area size, 2000 water year.

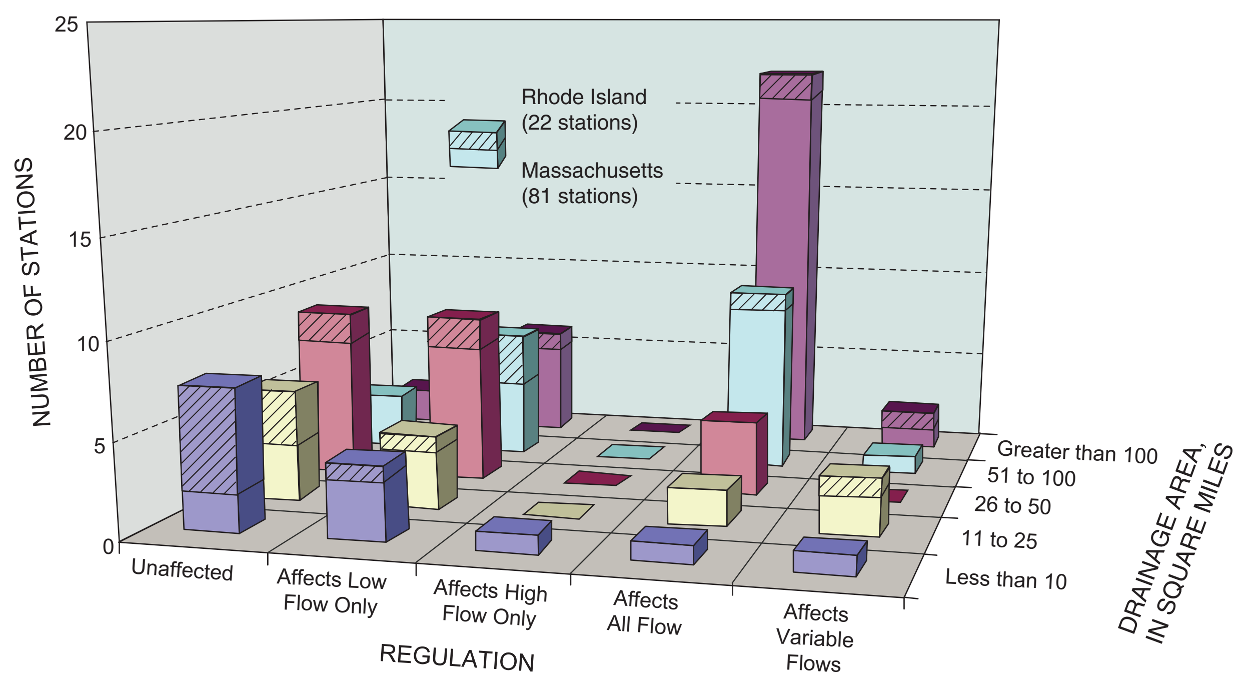

Figure 16. Number of active U.S. Geological Survey streamgage stations in Massachusetts and Rhode Island by drainage-area size and regulation, 2000 water year.

Regulation by drainage area and region: Only 26 of 103 active stations in Massachusetts and Rhode Island are unaffected by regulation; of these, 17 are in Massachusetts and 9 are in Rhode Island (table 5). About half the bins, (regions and various drainage-area-size classes) have no unregulated stations. The greatest number of unregulated stations is represented by drainage areas between 26 and 50 mi^2 in the Coastal Lowlands (total of six stations in Massachusetts and Rhode Island combined). Furthermore, only one unregulated station is operated in the Western Highlands, no unregulated stations are operated with drainage areas greater than 51 mi^2 in the Central Uplands, and only one unregulated station is operated with any drainage less than 10 mi^2 in the Central Uplands in either Massachusetts or Rhode Island. The number of stations currently in operation in each drainage-area range by region indicates a paucity of unregulated stations.

The number of stations suitable for low-flow analysis increases by one when stations affected by regulation at high flows only are considered; this station was in the Coastal Lowlands of Massachusetts with a drainage area less than 10 mi^2. The number of stations suitable for high-flow analysis (those affected at low flow only) increases slightly for each region and most drainage-area size classes (table 6). Thirty-four stations in Massachusetts and three stations in Rhode Island are unaffected by regulation at high flow, but 83 percent of these have drainage areas greater than 50 mi^2, and 37 percent of these are in the Central Uplands (table 6).

Table 5. Number of active U.S. Geological Survey streamgage stations unaffected by regulation, tabulated by drainage-area range and physiographic region in Massachusetts and Rhode Island, 2000 water year

Region	Drainage-area range in square miles				
	Less than 10	10 to 25	26 to 50	51 to 100	Greater than 100
Massachusetts					
Coastal Lowlands	2	0	5	2	2
Central Uplands	0	3	2	0	0
Western Highlands	0	0	0	1	0
Rhode Island					
Coastal Lowlands	3	2	1	0	0
Central Uplands	1	1	1	0	0

Table 6. Number of active U.S. Geological Survey streamgage stations unaffected by regulation at high flows, tabulated by drainage-area range and physiographic region in Massachusetts and Rhode Island, 2000 water year

Region	Drainage-area range in square miles				
	Less than 10	10 to 25	26 to 50	51 to 100	Greater than 100
Massachusetts					
Coastal Lowlands	1	2	2	0	6
Central Uplands	0	0	2	6	7
Western Highlands	0	0	1	3	4
Rhode Island					
Coastal Lowlands	0	0	0	0	0
Central Uplands	0	0	0	1	2

OBSERVATION-WELL METRICS

The observation-well network comprises 160 wells in Massachusetts and 40 wells in Rhode Island. In Massachusetts, the network includes 57 wells on Cape Cod, 10 wells on Martha’s Vineyard, and 10 wells on Nantucket; the high proportion of observation wells on Cape Cod and the Islands reflects the importance of ground water as the sole source of drinking water. For this reason, observation-well metrics have been separately identified for Cape Cod and the Islands. The Rhode Island network includes two wells on Block Island.

About 6 percent of the observation wells in Massachusetts, mostly in the Coastal Lowlands, are equipped with continuous data recorders; of these, nine are telemetered. In Massachusetts, 73 percent of the observation wells are measured manually at monthly intervals; and 21 percent of the wells are measured bimonthly, all of which are on Cape Cod. In Rhode Island, most observation wells are measured manually at monthly intervals, but four were equipped with continuous recorders during the 2000 water year.

Record Length

The lengths of record for all observation wells in the Massachusetts network, range from 6 to 65 years, with a median of 26 years. For Cape Cod and the Islands, record lengths of observation wells range from 10 to

51 years and have a median of 26 years; 85 percent of these have more than 20 years of record, but only 11 have records that date back to 1962 or earlier, and are thus long enough to encompass the most severe drought of record in this region (fig. 17). Record lengths for mainland Massachusetts observation wells range from 6 to 65 years and have a median length of 36 years; nearly 70 percent of these have records from the 1960s drought. Record lengths of Rhode Island observation wells range from 9 to 57 years with a median length of 11 years.

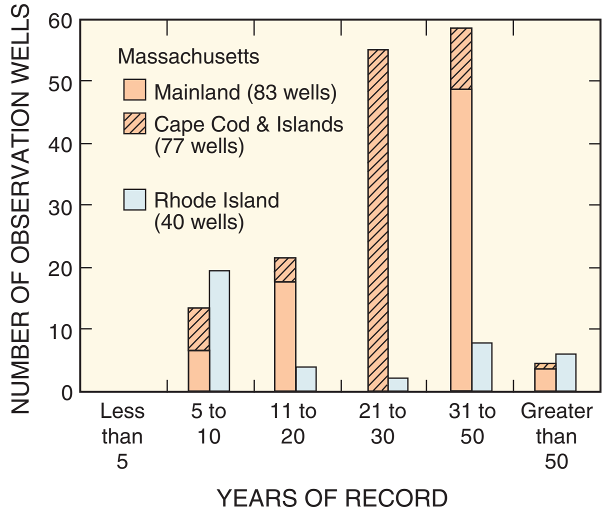

Figure 17. Record length of observation wells reported by the U.S. Geological Survey in Massachusetts and Rhode Island, 2000 water year.

Physiographic Region

Of the 200 observation wells in the Massachusetts and Rhode Island monitoring network, about two thirds (67 percent) are in the Coastal Lowlands, 24 percent are in the Central Uplands, and 9 percent are in the Western Highlands. Within mainland Massachusetts, about 46 percent of the observation wells are in the Coastal Lowlands, 33 percent are in the Central Uplands, and 21 percent are in the Western Highlands. In Rhode Island, 52 percent of the observation wells are in the Coastal Lowlands, and 48 percent are in the Central Highlands.

Geologic Material

Observation wells in Massachusetts and Rhode Island are mostly (80 percent) finished in sand and gravel, 19 percent are finished in till, and 1 percent (three wells) are finished in bedrock. In mainland Massachusetts, observation wells have a similar distribution—75 percent are finished in sand and gravel, 21 percent are finished in till, and 4 percent are finished in bedrock. Observation wells on the Cape and Islands are all finished in sand and gravel. In Rhode Island, half of the observation wells are finished in sand and gravel, and half are finished in till. The Rhode Island network does not have any wells finished in bedrock.

Observation wells in mainland Massachusetts and Rhode Island finished in sand and gravel are about three to four times more numerous than wells finished in till across each of the three physiographic regions (fig. 18). In the Massachusetts mainland Coastal Lowlands, Central Uplands, and Western Highlands, about 77, 68, and 83 percent of wells are finished in sand and gravel, respectively; 20, 25, and 17 percent of wells are finished in till, resepctively; and 3, 7 and 0 percent are finished in bedrock, respectively. In Rhode Island Coastal Lowlands and Central Uplands, about 62 and 37 percent of wells are finished in sand and gravel, respectively, and 38 and 63 percent of wells are finished in till, respectively.

Well Depth

Depths of observation wells below land surface in Massachusetts and Rhode Island range from 10 to 740 ft, with a median depth of 32 ft. In mainland Massachusetts, depths of observation wells below land surface range from 11 to 740 ft, with a median depth of 25 ft; well depths on Cape Cod and the Islands range from 10 to 294 ft, with a median depth of 53 ft. In Rhode Island, depths of observation wells below land surface range from 10 to 121 ft, with a median depth of 20 ft.

Depths of observation wells below land surface finished in sand and gravel (fig. 19*A*) range from 12 to 71 ft in mainland Massachusetts (median depth of 27 ft), 10 to 294 ft in the Cape and Islands (median depth of 53 ft), and 10 to 121 ft in Rhode Island (median depth of 28 ft). Depths of observation wells below land surface finished in till (fig. 19*A*) range from 11 to 39 ft in mainland Massachusetts (median depth of 21 ft) and 10 to 52 ft in Rhode Island (median depth of 18 ft). On average, observation wells in mainland Massachusetts and Rhode Island finished in sand and gravel are deeper than wells finished in till. Observation wells finished in bedrock are generally deeper than sand and gravel wells. Depths of observation wells across different physiographic regions and states are not distinctly different, except that wells on the Cape and Islands tend to be about twice the depth of wells in other regions (fig. 19*B*).

Installing a ground-water observation well by a rotary drill rig.

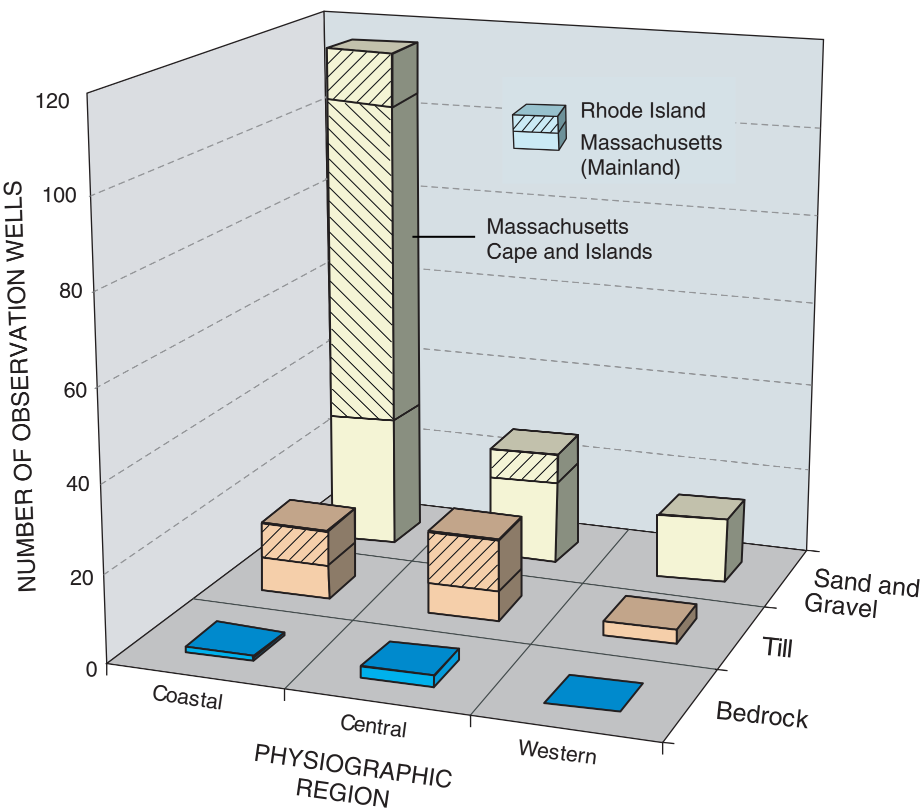

Figure 18. Number of observation wells in the 2000 water year by physiographic region and type of geologic material in which the well is finished.

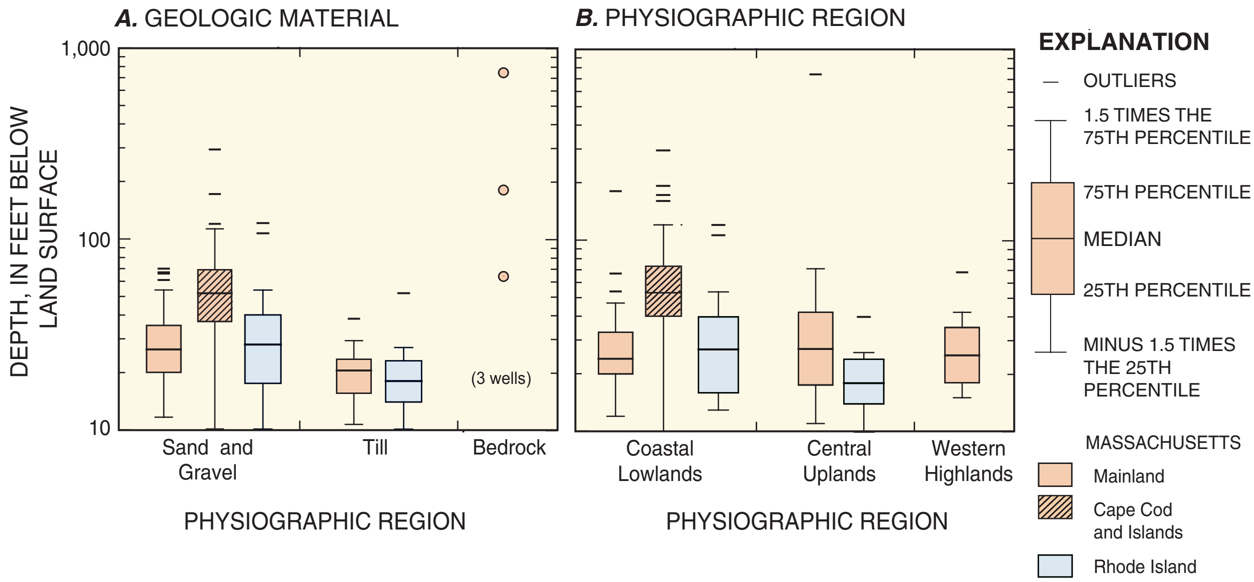

Figure 19. Depths of observation wells by (*A*) type of geologic material, and (*B*) physiographic region reported by the U.S. Geological Survey in Massachusetts and Rhode Island, 2000 water year.

FUTURE DIRECTIONS OF THE MONITORING NETWORK

For nearly 100 years, the streamflow and observation-well network of the USGS in Massachusetts and Rhode Island has provided hydrologic data for water-resources management, issuance of flood warnings, recreational, and numerous other purposes. Public and private interests have benefited from improvements in monitoring technology and from dissemination of historical and near real-time data through the Internet. The future monitoring network will continue to incorporate advances in technology to meet the needs of cooperators and the public.

The technology of the collection and distribution of near real-time hydrologic data has improved rapidly over the last decade. Future advances in technology will likely improve accuracy and reliability over a wide range of conditions. An example of one technology under investigation is non-contact stage and flow sensors, which have the potential to make streamflow measurements safer, cheaper, and at least as accurate as traditional measuring techniques. This technology would be especially beneficial for obtaining discharge measurements during flood conditions or in dangerous locations such as confined storm drains.

Acoustic Doppler Velocity Meters (ADVMs) have made it possible to produce accurate discharge records efficiently where conventional monitoring techniques yield unsatisfactory results because of variable backwater conditions or poor stage-discharge relations (Morlock and others, 2002). This technology could be cost-effective at stations that are regularly affected by beaver activity, where considerable time is spent correcting stage-discharge relations caused by dams only to yield records of poor or uncertain quality. In addition, the technology would eliminate the need to remove beavers in order to maintain a good-quality discharge record.

A near-term goal at streamgage stations is to completely equip them with DCPs and increase the frequency of transmission of data from every 4 hours to every hour at selected sites. This improvement would make data from the entire network available in near real time and could improve flood warnings that can save lives and prevent property damage.

Continued upgrades to the observation-well network are also anticipated in hydrologically sensitive areas in the near future. Improvements may include installation of continuous recording equipment, telemetry (DCPs), and use of the ROBOWELL (Granato and Smith, 2002) where near real-time water-quality monitoring is a consideration. Additional observation wells finished in bedrock are also likely as communities seek new sources of water supply in bedrock aquifers.

Cooperator needs evolve as development pressure puts greater strain on limited water resources. For example, increased demands for public and private water supplies will likely initiate additional State-mandated monitoring to provide minimum flow information in streams and rivers. Whereas these needs dictate the need for additional data in stressed basins, the continued operation and enhancement of stations that provide hydrologic information at unregulated sites is essential for regional hydrologic analysis. Applications like STREAMSTATS would not be possible without stations that provided a relation between partial record or short-term record sites to long-term unregulated stations. In an era of decreased financial resources and increasing demands for hydrologic information in stressed basins, the USGS and its cooperators will be challenged to maintain a balanced network that satisfies all these needs.

High-water discharge measurement made from a boat on the Housatonic River at Great Barrington, Massachusetts (station number—01197500).

Although the streamflow and observation-well network provides needed information on the hydrologic conditions of Massachusetts and Rhode Island, this network is generally viewed as two independent networks, despite the degree of hydraulic connection between ground-water and surface-water resources. It has become increasingly apparent, however, that ground water and surface water need to be managed as a single resource; information about the interconnection of ground and surface water is fundamental for their effective management (Winter and others, 1998). To assist managers in meeting this need, the existing streamflow and ground-water-level data could be analyzed for interactions between ground water and surface water and the influences they exert on each other. The design of future enhancements to the network could be based upon the understanding that surface water and ground water represent a single resource so that all appropriate data are collected for use by water-resource managers.

SUMMARY

Streamflow and ground-water-level data are used for a variety of purposes for water-resources planning and design, hydrologic research, and operation of water-resources projects. This data is routinely collected by the U.S. Geological Survey (USGS), in cooperation with other Federal, State and local government agencies through the operation of a network of 103 streamgage stations and 200 ground-water observation wells in Massachusetts and Rhode Island (active during the 2000 water year). Since continuous streamflow gaging began nearly 100 years ago (1904) on the Connecticut River at Sunderland (moved to Montague City in 1929) in Massachusetts, increases in the number of stations in the network usually followed floods or droughts; these events made clear the importance of this hydrologic information.

The collection, processing, and dissemination of hydrologic data collected by the USGS have continually improved over the century. In the 2000 water year, about 70 percent of streamgage stations and a few, but growing number of observation wells in Massachusetts and Rhode Island, have been equipped with digital collection platforms that transmit data by satellite every 4 hours. Twenty-one of the streamgage stations are also equipped with precipitation recorders. This near real-time data, along with most historical data collected at all stations, are available over the Internet at no charge.

The streamflow-monitoring network was evaluated with respect to several metrics that affect potential uses of the data. These metrics include record length, effects of regulation, distribution by physiographic region, drainage-basin size, physical basin characteristics and combinations of these factors. Collectively, 71 percent of the active stations in Massachusetts and Rhode Island have 30 or more years of record and most of these have more than 50 years of record. Most stations are affected by regulation; although data from stations affected by regulation are useful for specific water management purposes, it diminishes the usefulness of data from these stations for many types of hydrologic analysis. Only 26 of the 103 active streamgage stations operated by the USGS in Massachusetts and Rhode Island are in basins unaffected by regulation; of these, 17 are in Massachusetts and 9 are in Rhode Island. The paucity of stations in unregulated basins is particularly evident when distributed across five drainage-area ranges; there are no unregulated stations in about half of these ranges. This underscores the importance of establishing and maintaining stations that are unaffected by regulation. Streamgage stations in Massachusetts and Rhode Island are mostly in drainage basins in the Coastal Lowlands (48 and 77 percent, respectively); fewer are in drainage basins in the Central Uplands (35 and 23 percent, respectively) and 12 percent are in drainage basins in the Western Highlands (all in Massachusetts). Basin slopes are generally least for stations in the Coastal Lowlands and largest in the Western Highlands; slopes of stations in the Central Uplands are generally about half those of the stations in the Western Highlands and about twice those for stations in the Coastal Lowlands. Coastal Lowlands stations are in drainage basins that are generally more urbanized and underlain by a greater percentage of sand and gravel than stations in drainage basins in the Central Uplands or Western Highlands. Drainage-basin size is typically the single most important explanatory variable in streamflow estimation techniques. Drainage areas range from 0.39 to 8,309 mi^2, but most stations have drainage areas between 10 and 100 mi^2 (55 percent of the stations in Massachusetts and 68 percent of the stations in Rhode Island).

The observation-well network comprises 200 wells; 80 percent of these wells (3 wells) are in sand and gravel, 19 percent are in till, and 1 percent are in bedrock. About 6 percent of the wells are equipped with continuous data recorders and about half of these are capable of transmitting data in near real time. The record length for all observation wells ranged from 6 to 65 years; the median record length is 26 years for wells in mainland Massachusetts, 26 years for Cape Cod and Island wells, and 11 years for Rhode Island wells. The depth of all observation wells below land surface ranges from 10 to 740 ft. The median depth of observation wells is 26 ft for wells finished in sand and gravel, 21 ft for wells finished in till, and 181 ft for wells finished in bedrock. Generally, observation wells on Cape Cod and the Islands are about twice as deep as wells in other areas of the State.

The goal of the USGS streamgage station and observation-well network is to provide relevant and timely hydrologic information to the Nation, its cooperators, and to the public. Cooperator needs evolve as development pressure puts greater strain on limited water resources. Although this often requires additional data in stressed basins caused in part by the effects of regulation, the continued operation and enhancement of stations that provide hydrologic information at unregulated sites is essential for regional hydrologic analysis. In an era of decreased financial resources and increasing demands for hydrologic information in stressed basins, the USGS and its cooperators in Massachusetts and Rhode Island will be challenged to maintain a balanced network that satisfies all needs.

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